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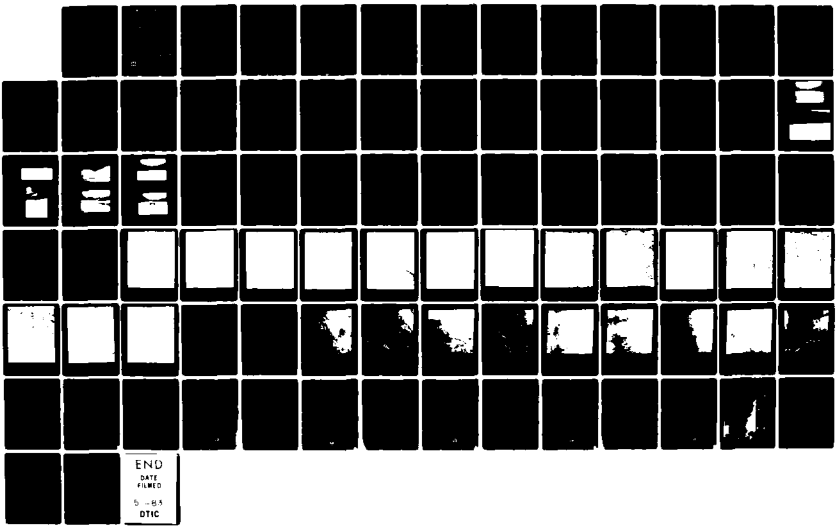

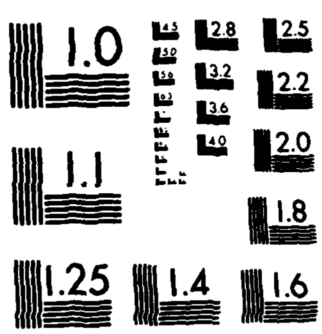

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SEISMIC EVALUATION CAUSATIVE FAULT STUDY

(1)

MISSOURI RIVER
OAHE DAM - LAKE OAHE
SOUTH DAKOTA

AUGUST 1982

US Army Corps of Engineers
Omaha District

DEPARTMENT OF THE ARMY
OMAHA DISTRICT CORPS OF ENGINEERS
6014 U.S. POST OFFICE AND COURTHOUSE
OMAHA NEBRASKA 68102

REPLY TO
ATTENTION OF

MROED-FC 25 August 1980

SUBJECT: Causative Fault Analysis, Oahe Project

Division Engineer, Missouri River
ATTN: MROED-G

1. Reference MRD letter subject, "Design Earthquakes for the Main Stem Dams of the Missouri River", dated 2 October 1978. The causative fault study and investigation of the 31 December 1961 earthquake cited in the third indorsement have been completed. Three copies of the Causative Fault Analysis are inclosed.

2. The investigation into the phenomena caused by the 31 December 1961 earthquake consisted of researching construction records, engineering files and newspaper articles, and conducting personal interviews with personnel who were at the project at that time. This investigation did not reveal any adverse or damaging effects to either the dam or appurtenant structures.

3. The Causative Fault Analysis failed to identify a causative fault related to earthquakes in central South Dakota. Much of the work done for the study is also coincidental to the dams downstream of Oahe. Thus, we consider that this study and the findings are applicable to Big Bend, Ft. Randall and Gavins Point dams.

4. The state of North Dakota is nearly aseismic. Work to date consisting of literature search and review of low and high altitude photographs has not revealed causative faults within 100 miles of Garrison Dam. For these reasons, we do not intend to conduct a more detailed study concerning causative faults in the vicinities of Garrison, Pipestem and Bowman-Haley dams.

5. Design earthquakes with accelerations of 0.10g and 0.15g at the dam sites will be used to determine a range of safety factors in the seismic evaluations of these dams. The higher acceleration was recommended by Dr. Herrmann in his report, "Seismicity Study and Design Earthquake for Missouri River dams in North Dakota and South Dakota." An acceleration of this level is considered to be very conservative and have a very long return period. The lower acceleration is in line with paragraphs 2b(4) and (5) of 2nd Indorsement dated 25 January 1979,

MROED-FC 25 August 1980
SUBJECT: Causative Fault Analysis, Oahe Project

where it was stated that this value was sufficiently conservative for sites where recurring seismicity, capable faults or evidence of source areas within 75 miles were not present.

FOR THE DISTRICT ENGINEER

1 Incl (trip)
as

R. G. BURNETT
Chief, Engineering Division

DTIC
COPY
INSPECTED
2

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MRDED-G (25 Aug 80) 1st Ind
SUBJECT: Causative Fault Analysis, Oahe Project

DA, Missouri River Division, Corps of Engineers, PO Box 103,
Downtown Station, Omaha, Nebraska 68101 15 September 1980

TO: District Engineer, Omaha, ATTN: MROED-FC

1. The Causative Fault Analysis is returned for further study and revision in accordance with the attached comments (Incl-2). A more in-depth treatment of tectonic source geometry, attenuation and seismic history should be included.

2. Revisions to the report should be based on additional studies of published and unpublished reports, geophysical records and drilling records, and by field work.

3. Upon completion of the geological and historical research, it is anticipated that the probability analysis will be repeated using weighted site and source parameters to arrive at an assessment of seismic risk based on both geology and seismology.

FOR THE DIVISION ENGINEER:

for J.J. Johnson
ARTHUR D. DENYS
Chief, Engineering Division

2 Incl
added 1 incl
as

MROED-FC (25 Aug 80) 2d Ind
SUBJECT: Causative Fault Analysis, Oahe Project

DA, Omaha District, Corps of Engineers, Omaha, NE 68102 29 November 1982

TO: Commander, Missouri River Division, ATTN: MRDED-G

Subject report has been revised in accordance with 1st Indorsement review comments. Two copies are inclosed for your approval.

FOR THE COMMANDER:

R. G. BURNETT
Chief, Engineering Division

1 Incl
wd incl 1 & 2
Added 1 incl:
3. as (dup)

MRDED-G (25 Aug 80) 3rd Ind
SUBJECT: Causative Fault Analysis, Oahe Project

DA, Missouri River Division, Corps of Engineers, PO Box 103,
Downtown Station, Omaha, Nebraska 68101   18 January 1983

TO: CDR USACE (DAEN-CWE-BB) WASH DC 20314

1. We have reviewed the report SAB, and recommend approval.

FOR THE COMMANDER:

JJ Johnson

Incl (1)
wd 1 incl

JJ

WILLIAM P. TODSEN, P.E.
Chief, Engineering Division

DAEN-CWE-BB (25 Aug 80) 4th Ind
SUBJECT: Causative Fault Analysis, Oahe Project

HQ, U.S. Army Corps of Engineers, Washington, D.C. 20314 16 February 1983

TO: Commander, Missouri River Division, ATTN: MRDED-G

Approved.

FOR THE COMMANDER:

wd all incl

LLOYD A. DUSCHA, P.E.
Chief, Engineering Division
Directorate of Civil Works

MRDED-G (25 Aug 80) 5th Ind
SUBJECT: Causative Fault Analysis, Oahe Project

DA, Missouri River Division, Corps of Engineers, PO Box 103,
Downtown Station, Omaha, Nebraska 68101   7 March 1983

TO: Commander, Omaha District, ATTN: MROED-FC

Forwarded.

FOR THE COMMANDER:

WILLIAM P. TODSEN, P.E.
Chief, Engineering Division

Incl
wd

MISSOURI RIVER
OAHE DAM-LAKE OAHE
SOUTH DAKOTA

SEISMIC EVALUATION

CAUSATIVE FAULT STUDY

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PROJECT C6548
DISK 4-C

CAUSATIVE FAULT ANALYSIS
OAHE DAM SEISMIC EVALUATION

1. Introduction

1.1 Purpose. The present study was conducted to determine if an earthquake producing fault (causative fault), capable of generating a damaging earthquake in the vicinity of Oahe Dam, could be identified. Although South Dakota has exhibited a relatively low level of seismic activity, the proximity of the 31 December 1961 Pierre earthquake prompts a detailed study. The approximate epicenter location was about 5-1/2 miles southwest of the dam, at N44.4°, W100.5°. The focus occurred at a depth of approximately 10 miles (16 kilometers). The earthquake effects were felt over an area of about 13,100 mi^2 (34,000 km^2), with slight damage reported in Pierre, ranging from a cracked concrete floor to fallen plaster. Intensity (MM) and magnitude (m_b) have been estimated at V to VI and 4.5, respectively (Nuttli and Herrmann, 1978), with an acceleration of approximately C.1g and a duration of 15 to 20 seconds at the epicenter. An inspection of Oahe Dam afterwards did not reveal any damage, and some beneficial consolidation of softer sediments may have occurred.

1.2 Scope. This study consists of: (a) A review of existing literature, (b) a remote sensing lineament study, and (c) field investigation. Existing literature includes published reports, geologic maps, lineament analyses and geophysical data. The present lineament study includes an examination of standard aerial photo index sheets, high altitude photography and Landsat imagery, and the preparation of a linear-feature map. A detailed study area having a 100-mile radius from Oahe Dam was selected. Much of the data studied extends beyond this area. Some detailed data, such as geologic maps and high altitude photography, did not completely cover the 100-mile radius about the dam.

2. Geology of South Dakota.

2.1 Surficial Geology. Surficial geology of South Dakota has been compiled by Petsch (1952). The area east of the Missouri River is mostly covered by glacial drift of Pleistocene age. Exceptions to this are: (1) extensive lake deposits, also of Pleistocene age, in the James River area of Brown and Spink Counties; (2) Cretaceous sediments exposed along the Missouri River trench; (3) The Sioux Quartzite, metamorphic rocks of Precambrian age, exposed in southeast South Dakota, particularly in the Sioux Falls area; and (4) granitic rocks of Precambrian age which crop out near Milbank, in the northeast corner of the state. Cretaceous sediments predominate west of the Missouri River, as shown on Plate 7. Cretaceous sediments are represented primarily by the Hell Creek, Fox Hills, and Pierre Shale Formations. The Ft. Union and Ludlow-Cannonball Formations, of Paleocene age, are exposed in northwest South Dakota and the Arikaree and White River Formations of Oligocene age are exposed in southwest South Dakota. Also in southwest South Dakota are the Sand Hills, of Recent age, which are reworked material of the Ogallala Formation. The Black Hills Uplift in the far west part of the state contains exposures of Precambrian igneous and metamorphic rocks and Cenozoic igneous rocks. Upturned sedimentary rocks of Paleozoic and Mesozoic age encircle the uplift.

2.2 Structural Domains. Plate 1 shows three structural domains represented in South Dakota: (1) The Black Hills Uplift, (2) The Williston Basin and, (3) The Sioux Ridge. The Black Hills Uplift occupies the far western part of the state and is excluded from consideration of causative faults due to its distance from the study area. The southern edge of the Williston Basin occupies the northwestern portion of the state. The Williston Basin has persisted as a structural low throughout most geologic time, accumulating vast amounts of sedimentary material. The northwest trending Sioux Ridge is present in southeast South Dakota. The Sioux Ridge is a basement high covered by a Sioux Quartzite sheet and extends from extreme southeast to central South Dakota.

2.3 Basement Rocks. An inferred basement fault, located in Jones County in south central South Dakota, is shown on Plate 1, Preliminary Map of the Precambrian Surface of South Dakota (Steece, 1961). The northeast trending inferred fault appears to be based primarily upon only two deep oil test wells which penetrate basement rocks. Lidiak (1971) reported a northeast trending fault in the basement rocks of northeast South Dakota (Plate 2). This inferred fault, which is nearly on trend with the Jones County feature, extends from Minnesota to central South Dakota, where it appears to be truncated by a northwest trending fault. Both of these trends, northwest and northeast, have expression on the Vertical Intensity Magnetic Map of South Dakota (Petsch, 1967). Morey and Sims (1976) confirmed the presence of the northeast trend discussed by Lidiak (1971), as interpreted from aeromagnetic and gravity data and scattered outcrop. They interpret the feature as a boundary between Precambrian rocks of different age; a greenstone - granitic complex to the north and granitic and mafic gneisses to the south of the trend. This Precambrian boundary is also shown on Plate 2. These northeast trending features are included in a much larger feature known as the Colorado Lineament, which is described in section 3.5.

3. Previous Lineament Studies.

3.1 General. The concept of linears and lineaments was first applied to aerial photo interpretation and then later applied to small scale imagery such as from Landsat. The discussion of fracture traces by Lattman and Matzke (1961) has had a strong influence on current interpretations of lineaments. The following is an excerpt describing the probable nature and occurrence of these features:

> "Fracture traces, which probably represent zones of joint (and small fault) concentration, are parallel to the trends of major joint sets in areas of flat to gently dipping rocks...Steeply dipping faults may bound areas of different fracture-trace orientations. The orientations are, however, relatively constant within blocks bounded by such faults..."

Hoppin (1974) further defined lineaments as "complex, composite, commonly interrupted, generally rectilinear regional tectonic features" and linears as "single, more local rectilinear elements..." Lineaments, therefore, are regional features which may give an indication of tectonic activity in an area.

3.2 Lineaments in Western South Dakota. Shurr (1978 and in press) has mapped lineaments on seven Landsat scenes of western South Dakota. Imagery of bands 5 and 7 for each scene were mapped for linear features. The operation was conducted, independently, by two workers. The majority of the lineaments mapped trend N60°E to N90°E or N30°W to N60°W. Two classes of linear features were observed: One class having an average length of 6.2 miles and another averaging lengths of 25 miles. The class of longer features was used to produce a lineament map of western South Dakota. These features are shown on Plate 2. Features without expression on the vertical magnetic intensity map were eliminated from the lineament map. Lineaments were ranked on the basis of frequency of observation (observed by one worker on band 5 or 7 through both workers on both bands 5 and 7). The remaining features were interpreted as reflecting attributes of the Precambrian basement. Shurr postulated that during deposition of the Pierre Shale, lineaments were the sites of tectonic activity. His study of stratigraphic markers in the Pierre inferred tectonic activity on northwest trending lineaments later than 78 m.y. ago and a shift in activity to northeast trending lineaments at approximately 72 m.y. ago. Expression of specific lineaments in Paleozoic rocks was found to be less clear than in Cretaceous sediments. Shurr suggested that the correspondence of lineaments to modern topographic features may indicate relatively recent tectonism, but there is no evidence to support this. He interprets the lineaments as the surface expression of major zones of weakness, subdividing the Precambrian basement into discrete blocks. He recognizes four blocks, corresponding to major tectonic features: A western block occupied by the Black Hills Uplift; a northern block occupied by the southern edge of the Williston Basin; a southern block occupied by the Sioux Uplift; and a central block, transitional step from basin to arch.

3.3 Computer Graphics. Sawatsky and Raines (in press) developed a procedure that combines conventional photo-interpretation with computer graphics and other computer programs. The program is an attempt to contribute objectivity and reproducibility to linear-feature analysis. Using 1:1,000,000 Landsat imagery, all linear features of natural origin are mapped. The linear-feature map is then digitized so that directional trends and linear-feature concentrations can be computed. This information is then integrated with all available geologic data to provide a geologic analysis (Raines, 1979). The procedure was applied to digitally enhanced Landsat imagery of south-central South Dakota. Eight hundred and eighty-eight line segments, averaging 2.9 miles in length, were mapped. The major lineaments identified by Raines were interpreted as basement zones of instability, which have influenced Cretaceous sea-floor topography and thus depositional environment. These major lineaments and others are shown on Plate 2.

3.4 Stream Alignment in Western South Dakota. Many linear-features in South Dakota, particularly west of the Missouri River, correspond to drainage courses. The master streams which predate, but now drain into the Missouri River, are notable examples. These alignments may be significant in that they may be controlled by geologic structure controlled by tectonism. The relationship of tectonism to location of big rivers has been discussed by Potter (1978). However, preglacial drainage appears to have been topographically controlled, since drainage was to the northeast into Hudson's Bay. A northwest-southeast stream alignment can also be observed. While the orientation of fracture patterns can certainly influence stream orientation, White (1961) suggested that the prevailing winds may influence smaller streams having a northwest-southeast alignment. White suggested that the accumulation of eolian materials in drainages, oriented other than northwest-southeast, would retard headward erosion, as compared with northwest-southeast drainages that are relatively free of eolian material.

3.5 Regional Seismicity and Lineaments. Many of the linear features may correspond with the larger feature known as the Colorado Lineament (Warner, 1978). This feature, shown in Plate 8, is described as a middle

Precambrian wrench fault system extending from northern Arizona to eastern Minnesota, over 1,000 miles (1,600 km) long and 40 miles (65 km) wide. The Colorado Lineament passes from southwest to northeast through South Dakota, in the general area just south of Pierre. The trend of this lineament was determined by deep borings that penetrated the Precambrian, and it correlates in some portions to gravity anomaly and magnetic trend maps. However, evidence is still sketchy due to the scarcity of deep holes to provide substantiation. Nuttli and Brill (1980) described the Colorado Lineament as a principle earthquake source zone for the Central United States, based on a strong spatial correlation between the historical record of earthquake epicenters with m_b greater than or equal to 4.5 and the boundaries of the Colorado Lineament. All earthquakes of m_b 4.5 or greater in South Dakota in the last 100 years, listed in the report, are located within the lineament boundary. The magnitude 4.5 earthquake was used in this determination as the lower limit for damaging earthquakes. A plot of decreasing earthquake magnitude events begins to scatter from the lineament boundaries and the lineament may not be a source zone for potentially damaging earthquakes. The Colorado Lineament is shown on Plate 8, along with earthquake epicenters with m_b equal to or greater than 3.0.

<u>3.6 Hazard Analysis of Oahe Dam</u>. In a draft report by Herrmann (1981), the Colorado Lineament is used as a source zone and the entire state of South Dakota used as another in a probabilistic seismic hazard analysis for the upper Missouri River basin. This analysis, based on the method developed by Cornell (1968), results in a predicted maximum peak acceleration of 0.06g with a 0.001 annual frequency. The probability curves are included in Appendix A. This analysis was calibrated with several other sites where deterministic analyses were previously performed, and the results are similar. Variations in the parameters of such analysis can cause significant changes in the results, therefore subjective factors must be weighted carefully. The low level of seismicity in the South Dakota area makes assigning seismicity to a particular source quite difficult. Based on the work by Nuttli and Brill (1980), the sources used by Herrmann appear to be the most

suitable for use in the analysis, considering the short and incomplete record of historical seismicity available.

4. Present Lineament Study.

4.1 General. The present lineament study was conducted in order to identify possible sites of causative faults. This study consisted of the mapping of linear-features and the integration of this data with all available geologic information. Aerial photo index sheets, high altitude photography and Landsat imagery were examined for linear-features. All available geologic maps within the 100-mile radius study area and maps of geophysical data were examined. Field investigations were then made at selected lineament sites.

4.2 Air Photo Index Sheets. Air photo index sheets at a scale of 1:40,000 were examined for linear features. Coverage included the entire area within a 100-mile radius of Oahe Dam, as shown on Plate 3. A search was made for prominent linear features having a length of at least 5 miles. Prominent topographic features or drainage alignments which were readily recognized on small scale imagery were not included. No prominent linear features were found.

4.3 High Altitude Photography. NASA false-color infrared photography of the Oahe area and Cheyenne, Bad, and White rivers were also examined for linear features. Most of the coverage was in stereo and at a scale of approximately 1:125,000. Linear-features, most less than 5 miles in length, were found on this photography. These features were unsuitable for presentation on a scale of 1:1,000,000, the original scale of the linear-feature map, and are shown diagrammatically on Plate 3. Less prominent features, which were at first not identified, were found when Landsat linear features were compared with the photography. Less prominent features were also found in "retrospect," when previously mapped faults were compared with the photography. Selected photographs with overlays showing lineaments are included in Appendix B.

4.4 Landsat Imagery. The Landsat imagery data were obtained from the multispectral scanner (MSS) aboard the Landsat satellite. The data have been converted from electronic signals to photographic images. The multispectral scanner measures the reflectance from earth over a unit area (pixel) of approximately 1.1 acres for each of four broad bands of the electromagnetic spectrum, arbitrarily numbered 4, 5, 6, and 7. The reflectance for each pixel is assigned a radiance value on a scale of 1 to 64. These radiance values are transmitted to earth. Images derived from a single band are printed in black and white. Shades of gray correspond to radiance values. Data from three bands (commonly bands 4, 5, and 7) are combined to produce false-color imagery. Since visual perception of shades of gray is limited, more information can, in general, be perceived by the use of color. Information loss can be eliminated by use of a digital format rather than "hard copy" imagery.

4.4.1 Coverage. Nine Landsat scenes, forming a three by three grid (250 X 320 miles) centered over Pierre, South Dakota, were utilized in the lineament study. Plate 4 shows the coverage, which includes central South Dakota, south-central North Dakota, and north-central Nebraska. Imagery was obtained by Landsat 2 May 1976. Single bands 4, 5, 6, and 7 were examined at a scale of 1:250,000. Color composites (Bands 4, 5, and 7) of computer enhanced data were examined at scales of 1:250,000 and 1:1,000,000. Linear-feature maps were derived from the 1:1,000,000 color composites included in Appendix C.

4.4.2 Linear-Feature Map. The linear-feature map shown on Plate 5 was produced by tracing linear and curvilinear features on acetate sheets overlain on 1:1,000,000 color composites. In general, all observed linear features, presumed to be of natural origin and having a length of at least 5 miles, were mapped. Some shorter features which were on trend with other linears were also mapped. Overlays from each of the nine Landsat scenes were assembled to form a composite map. The overlays were visually matched, using control points common to two or more scenes. The original imagery was not geographically correct and thus the linear-feature map contains slight

geographical errors. These errors were minimized whenever possible. Approximately 270 linear-features, averaging 15 to 20 miles in length, were mapped in the 100-mile radius area. The majority of the features lie west of the Missouri River. Many of those features east of the river are of obvious glacial or periglacial origin. Most features trend NW-SE, NE-SW and ENE-WSW. The latter set is primarily related to the Cheyenne, Bad, and White Rivers.

4.4.2.1 Comparison with High Altitude Photography. Several linear-features were compared with high altitude photography. A few features that were found to be cultural patterns were removed from the linear-feature map. Several Landsat features were not found on high altitude photography. This may be due to the segmental nature of linears or problems with scale including pixel size or resolution of the Landsat imagery. However, segments of most Landsat features that were compared with photography were found. These features have been shown in blue on Plate 5. Generally, these were subtle features not noted during original examination of the high altitude photography.

4.4.2.2 Proximity to Oahe Dam. A small number of linear-features, identified from Landsat imagery, lie in proximity to Oahe Dam. Several linear-features trend northwest-southeast and extend from Little Bend, approximately 30 miles northwest of Oahe Dam, to near Canning, South Dakota, about 17 miles east-southeast of the dam. Features along this trend were not found on high altitude photography and probably represent a composite of drainage patterns and field diagonals. Another northwest-southeast trending feature lies along the western shore of Lake Oahe, approximately 8 to 14 miles upstream of Oahe Dam. This feature appears on high altitude photography and has been mapped as exposure of the Verendrye and DeGray Members of the Pierre Shale. The feature appears to be of nontectonic origin. A northeast-southwest trending feature, which also appears on high altitude photography, parallels the dam axis, is on trend with the toe of Oahe Dam, and extends from the southwest to the cut slope above the outlet works channel. Deep borings at Oahe Dam, on either side of this trend, do not show displacement of the Pierre-Niobrara contract. The relative elevations of Pierre-Niobrara contract conform with a Pre-Pierre surface having a dip of

less than 1/10th degree. Other Landsat features follow the course of the Bad River. On high altitude photography, several subtle northeast trending linear-features can be seen south of Ft. Pierre.

4.4.2.3 "Skylab Structure". Raines, Bretz and Shurr (1979) discussed the "Skylab structure" at 103°W., 44°33'N. Mapping of marker beds suggests faulting. However, evidence for faulting is scant and additional investigation of the feature is anticipated by the authors. The feature appears on the linear-feature map on Plate 5, and is located approximately 132 miles west of Oahe Dam.

4.5 Field Investigations. A field investigation was conducted in June 1981 at sites readily accessible by automobile, where lineaments intersected highways or roads. Lineaments were selected from the NASA false-color infrared photographs included in this report in Appendix B. These were felt to be the best reference images for the field work conducted due to the scale, clarity, and distinctions of the vegetational differences. The sites investigated were primarily to the west of Pierre, due to the glacial cover over the eastern portion of the state. Areas of known lineaments were compared with adjacent areas for variations in: (a) Vegetation type; (b) vegetation health, heighth, and color; (c) soil color; (d) apparent moisture; (e) soil type; (f) present land use, including power lines, and grazing; (g) old land uses, including old roads, fence lines, canals, and trails; and (h) bedrock features, including resistant outcrops, varied color phases, concretions, and caliche. Of the sites investigated, only two produced evidence of faulting. Faulting at the sites indicated was slump type faulting associated with undercutting toes of slopes by road cuts or stream encroachment, as shown on Photos 5 and 6. Such slump faulting is common in the Pierre Formation, which is predominantly a marine compaction type shale with numerous bentonite seams and a notable lack of strength. This material was exposed at most of the sites investigated. The linearity of such slumping may be controlled by fracture traces as described by Lattman and Matzke (1961). Most of the lineaments clearly visible on the NASA photography and on satellite imagery were not observable on the ground. This was probably due to the large scale

of the lineaments and a gradual phase-in to adjacent areas to observers on the ground. A few features were discounted as being general linear trends of resistant bedrock members of the Pierre Formation, as shown in Photos 3 and 4; vegetational differences due to grazing or planting, as shown in Photo 1; or in one case, a relationship with an old, currently unused Indian trade route, as shown in Photo 8.

5. Discussion. Linear-feature maps are largely nonreproducible. Although the recognition of individual linears is subjective, major trends can be recognized on a consistent basis. Plate 6 shows a comparison between the linear-feature map and lineaments by Shurr (1978) and Raines (1979) and the major trends from the Vertical-intensity magnetic map of South Dakota (Petsch, 1967). Difficulty in the separation of closely spaced, criss-cross, and/or indistinct features and the masking of less prominent features by those already mapped, contribute to make linear-feature maps nonreproducible. Linear-features appear to be of various origins. While it is assumed that some linears may be of tectonic origin, this has not yet been demonstrated in South Dakota. Tectonism in basement rocks may be reflected at the surface by fault displacement or the close spacing of fractures and joints. With the exception of faults already mapped in the Black Hills and Badlands region, surface displacement has not been recognized in South Dakota. Based on the examination of Landsat imagery, high altitude and standard aerial photography, linear-features are generally found to represent surface features such as linear segments of drainage courses, drainage alignments, rock and soil contacts or markers, moisture/vegetational boundaries, and surface geologic structural features. Raines (Raines et al, 1979) generated a color-coded Landsat image (Vegetation density map) based on the ratio of the radiance values on bands 5 and 6. A strong relationship was found between the vegetation density map and geologic maps, particularly soils maps. A review of the historical seismicity for South Dakota does not reveal any earthquakes with m_b greater than 5.0. The field investigation of the lineaments selected did not reveal any major faulting at the surface capable of producing earthquakes. Most were not detectable on the ground, although they may be large scale concentrations of joints and fractures.

6. Discussion, Subsequent Investigation, Big Bend Dam. Since the completion of the principal effort of this investigation, a seismic hazard analysis has been made for Big Bend Dam. The Big Bend Dam study was accomplished by incorporating geologic data into Cornell's (1968) probabilistic method of analysis. This results in a deterministic-probabilistic approach in which seismotectonic provinces and zones are delineated. The analysis for Big Bend Dam concluded that the most severe seismic hazard for Big Bend Dam was a peak ground acceleration of 0.11g caused by an earthquake of magnitude $m_b = 5.6$, located at a point source 21 miles southeast of the dam. This earthquake has an annual frequency of 0.001. The Big Bend Dam seismic hazard analysis revealed that Oahe Dam is located in a seismotectonic subprovince (Sioux Ridge - Sioux Uplift) which is part of the larger Transcontinental Arch Seismotectonic Province. The largest potential earthquake with an annual frequency of 0.001 that could occur within the Sioux Ridge - Sioux Uplift Seismotectonic Subprovince would have a magnitude $m_b = 6.0$. The corresponding earthquake in the Transcontinental Arch Seismotectonic Province would have a magnitude $m_b = 6.4$. Utilizing Cornell's areal source analysis to determine the seismic hazard generated by these two events, the peak ground acceleration at Oahe Dam would be 0.12g and 0.07g, respectively. Refer to "Seismic Evaluation - Evaluation of Embankment and Foundation Liquefaction Potential, Big Bend Dam and Lake Sharpe," dated September 1982, for a detailed discussion of the deterministic-probabilistic method of analysis.

7. Summary and Conclusions. There is no evidence of surface ruptures caused by deep-seated faulting in the general area of the damsite. There has been no rupture of the surface in the last 10,000 years (Late Pleistocene). Seismic activity in South Dakota is slight, evidenced by small earthquakes occurring infrequently within the structural areas of the state. The field study of lineaments in South Dakota indicates they generally represent surface features such as drainage courses and alignments, rock and soil contacts or marker beds, moisture/vegetal boundaries and cultural features. No correlations can be made between linear features and historical seismicity for the area. A tenuous relationship can be made between gross structural domains

and historical seismicity. It is concluded that, because of the very low level of seismicity in South Dakota and the absence of surface ruptures, there is only an extremely low potential for an earthquake that could cause damage to Oahe Dam. The 1981 Hermann analysis, using the Colorado Lineament as a source zone, resulted in a predicted maximum peak acceleration of 0.06g. The 1982 Big Bend Dam analysis, using seismotectonic provinces as source zones, resulted in a predicted maximum peak acceleration of 0.12g.

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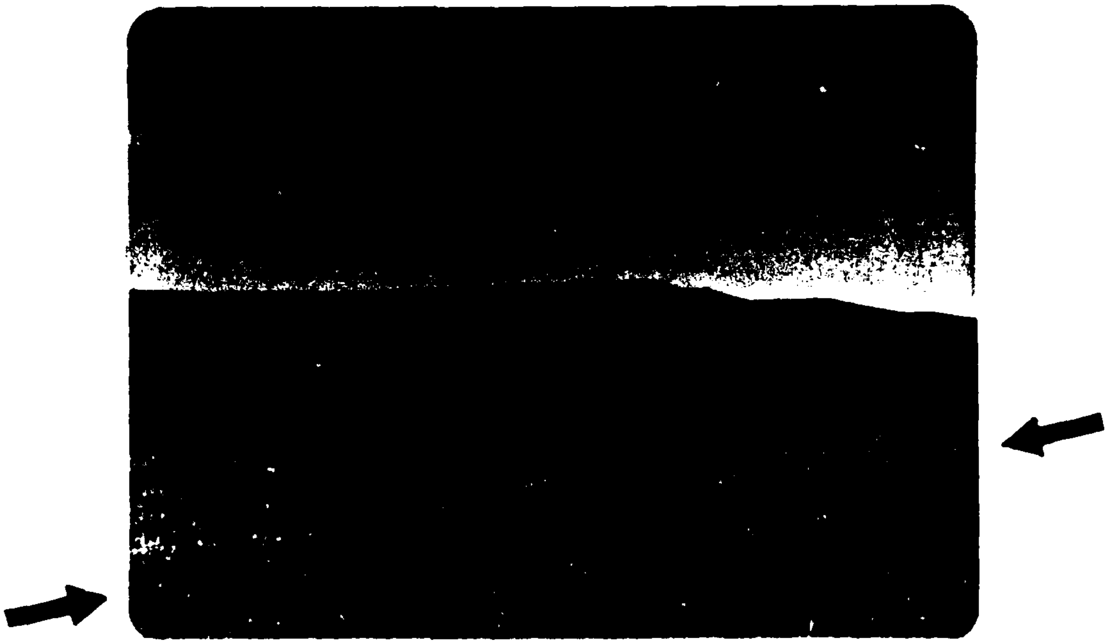

PHOTO NO. 1. Ground view of lineament on NASA photo, frame 2464. Note vegetation difference along fence line.

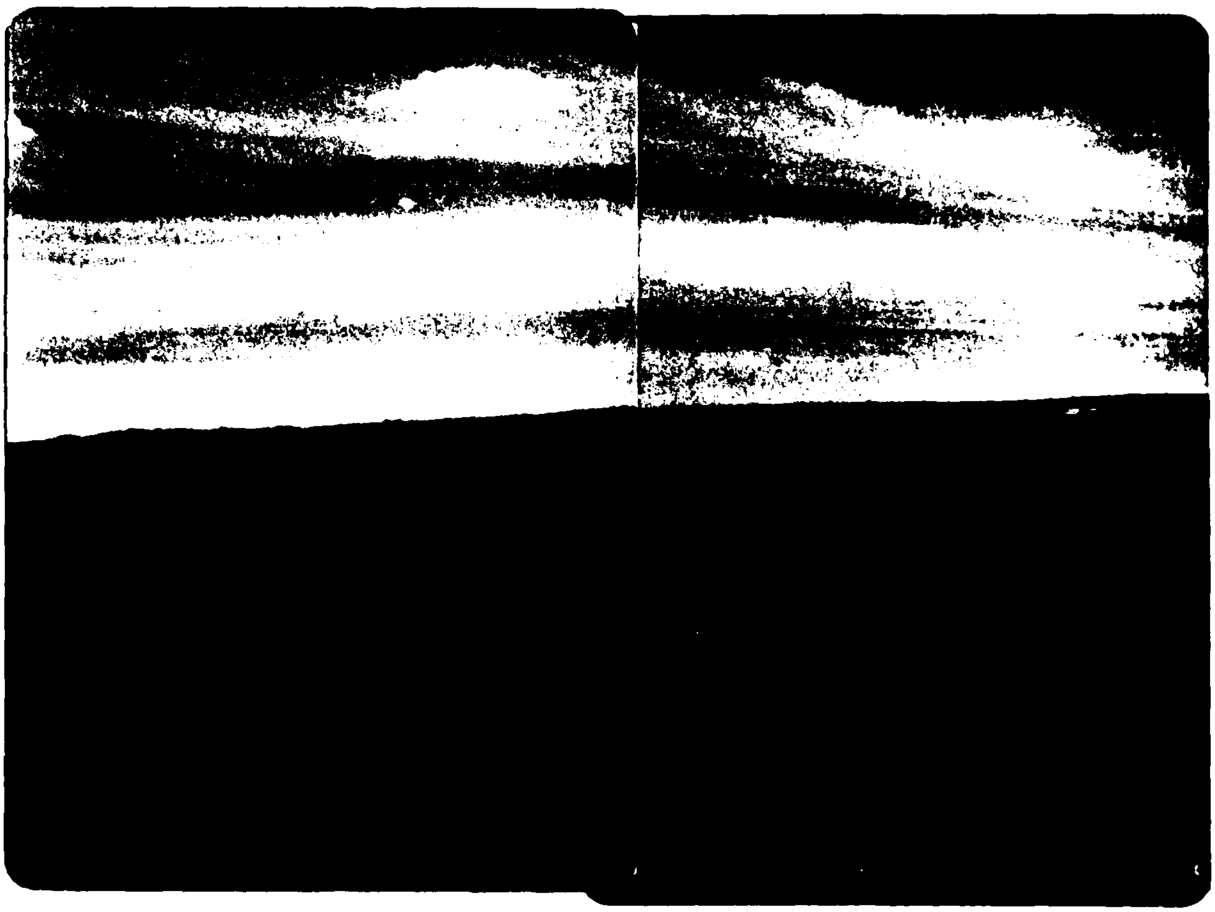

PHOTO NO. 2. Ground view along lineament on NASA photo, frames 2449 and 2450, looking SSW.

PHOTO NO. 3. View of lineament area shown on NASA photo, frame 2465. Note resistant outcrop in shale, with less vegetation.

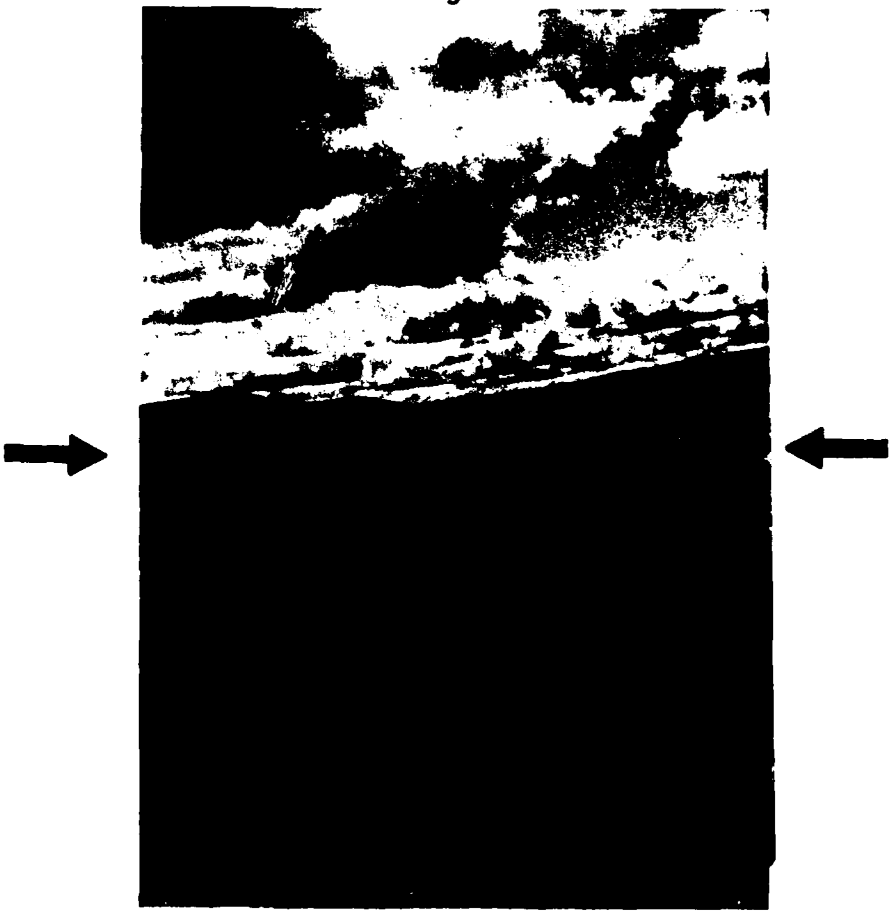

PHOTO NO. 4. Closer view of a shale outcrop with less vegetation.

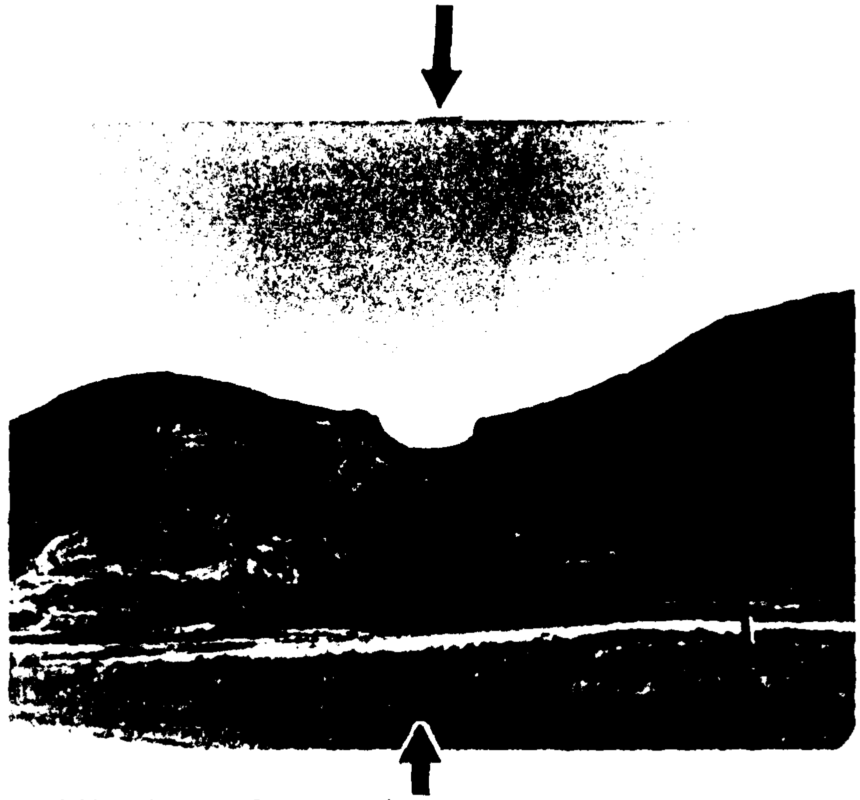

PHOTO NO. 5. Looking northeast at slumped area along lineament on NASA photo, frame 2465.

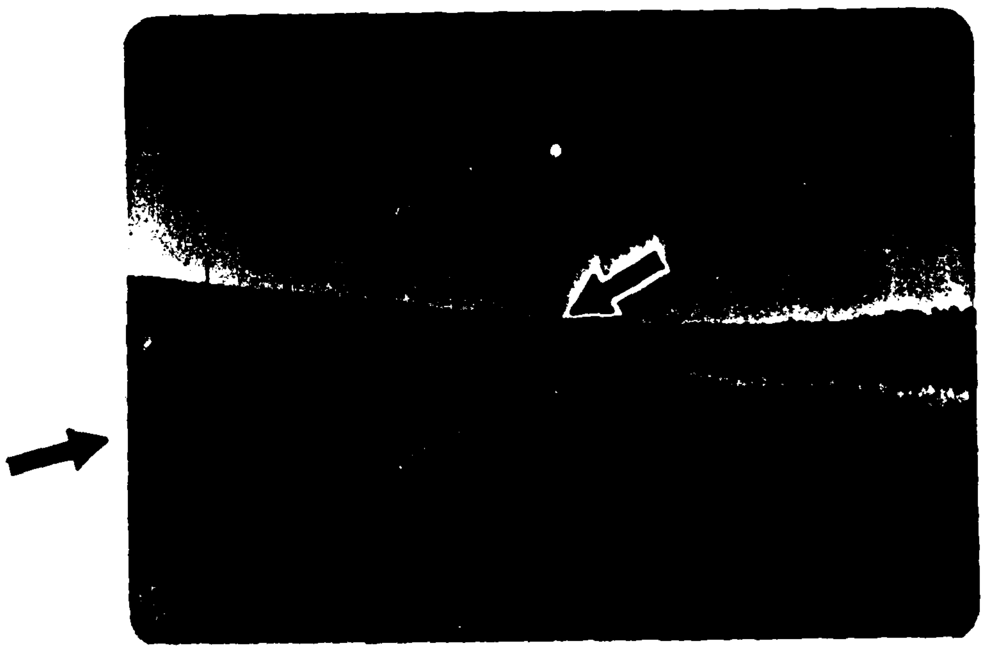

PHOTO NO. 6. Looking west along lineament shown on NASA photo, frame 4553. Note slumping along undercut toe of slope.

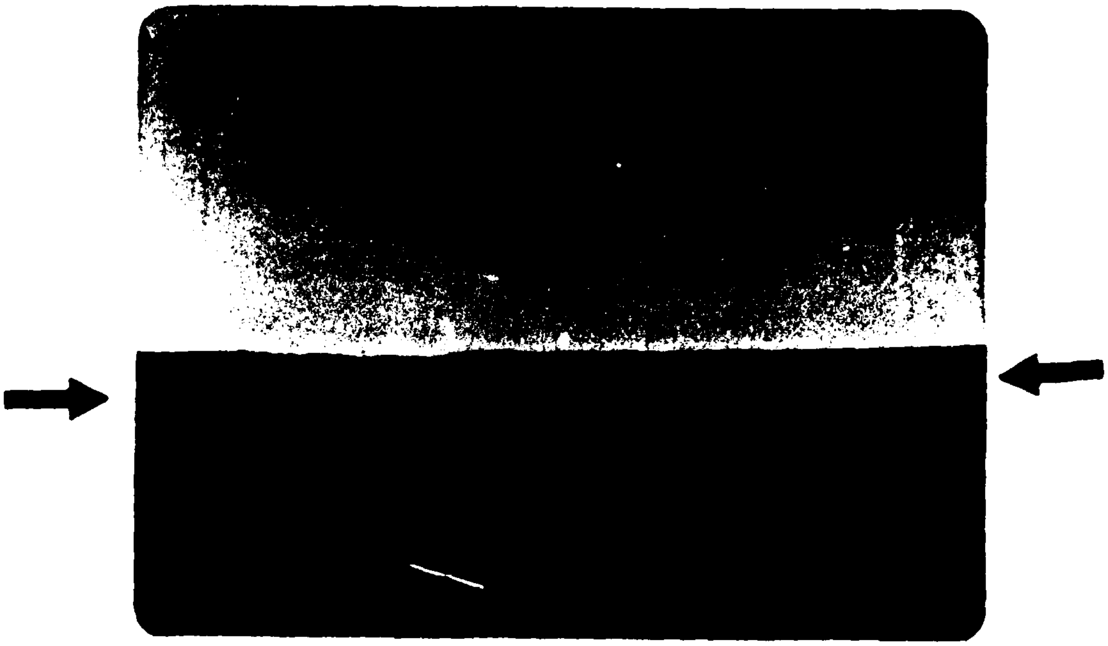

PHOTO NO. 7. View of same area shown on Photo No. 6, seen normal to river.

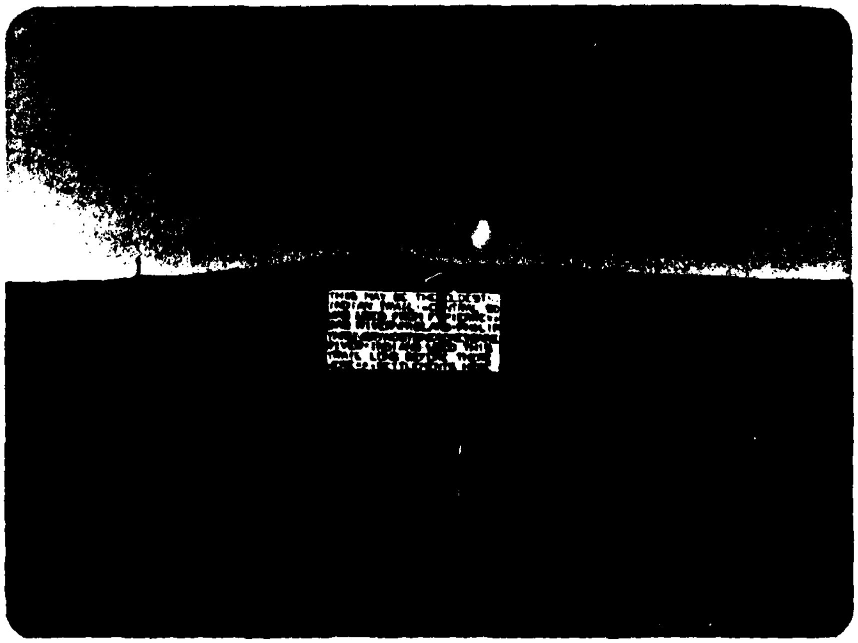

PHOTO NO. 8. Ground view of NASA photo, frame 2465, following Indian trail.

APPENDIX A

This appendix contains a subset of the Nuttli earthquake catalog together with a forward to the catalog by Nuttli. The results of Herrmann's March 1981 hazard analysis in terms of annual frequency and potential maximum earthquake magnitude are given for the Northern Great Plains and the Colorado Lineament following the Nuttli earthquake catalog.

CATALOG OF CENTRAL UNITED STATES EARTHQUAKES SINCE 1800 OF $m_b \geq 3.0$

Compiled by
Otto W. Nuttli
Saint Louis University

Note: The thousands of felt earthquakes which were aftershocks of the 1811-1812 New Madrid earthquakes are not included in this list. Their magnitude and number are greater than all the earthquakes which have occurred in the central United States since 1812.

EXPLANATION OF CATALOG

Columns 1, 2, 3 give the month, day and year, respectively, of the earthquakes. Columns 4, 5, 6 give the origin time in Universal Time (hour, minute, second, respectively). Column 7 gives north geographic latitude of the epicenter, in degrees. Column 8 gives west geographic longitude of the epicenter, in degrees. Column 9 gives the felt area, in square kilometers. Column 10 gives the epicentral intensity (M.M.). Column 11 gives the the body-wave magnitude. Column 12 gives the surface wave magnitude. Column 13 gives the explanation of how the magnitude was determined (s ee below). Column 14 gives the principal reference used in obtaining the parameters of the earthquake (see below).

EXPLANATION OF SYMBOLS IN COLUMN 13

A Magnitude determined from seismographic data

B Magnitude determined from fall-off of intensity with epicentral distance (see Nuttli, Bollinger and Griffiths, BSSA, vol. 69, 1979, pp. 893-909)

C Magnitude determined from felt area (see Nuttli and Zollweg, BSSA, vol. 64, 1974, pp. 73-85)

D Magnitude determined from epicentral intensity

E Very shallow earthquake, with relatively large epicentral intensity and small magnitude and felt area

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EVENTS WHICH ARE NOT EARTHQUAKES IN THE CENTRAL UNITED STATES

10 March 1828	In some lists the epicenter is mistakenly placed at Maysville, KY. The earthquake occurred in North Carolina or Virginia.
February 1857	No earthquake in New Madrid, MO area.
1865 to 1870	Duplication of 1860 earthquake in Minnesota.
19 November 1878	A duplication of the Cairo, IL earthquake of 19 November 1877.
31 October 1878	An explosion in Niles, MI.
08-09 Feb. 1899	Breaking up of ice at Chicago, IL.
31 December 1903	Dynamite explosion at Fairmont, IL.
09 February 1906	Mining activity in Michigan.
20 April 1906	Mining activity in Hancock, MI.
10 January 1907	Ice yielding in Menominee, MI.
20 February 1907	Landslide in Waldrun, AR.
1916	No earthquake in south central Iowa.
02 March 1924	Duplication of Kentucky earthquake of 02 April 1924.
20 July 1927	According to Moneymaker, this was a sharp local shock, accompanied by an explosive sound, and believed to have been an explosion.
20 September 1930	Duplication of Anna, Ohio earthquake of 30 September 1930 or 20 September 1931.
23 November 1940	Duplication of Griggs, IL earthquake of 23 November 1939.
15 January, 1966	Sonic booms at Texas-Louisiana border. 01, 02 03 Feb, 1966
06 July 1970	Rockburst at Leadwood, MO.

LIST OF EARTHQUAKES IN THE AREA WITH VERTICES
49N, 105W; 49N, 94W; 39N, 105W; 39N, 94W.

DATE			TIME		LAT	LONG	FELT AREA	INT	mb	MS	SYM	REF
		1860			46.0	94.8		6- 7	5.0		d	4
4	24	1867	20	22	39.2	96.3	800000	7	5.1		c	5
4	28	1867			40.7	95.8		4	3.8		d	4
2	9	1872			44.6	100.7		3	3.4		d	4
10	9	1872	16		42.7	97.0	8000	5	4.2		d	3
11	8	1875	10	40	39.0	95.7	21000	5	4.0		c	5
12	9	1875	9		40.7	95.8		3	3.4		d	4
8	17	1876	5	25	44.1	99.6		4	3.8		d	4
11	15	1877	17	45	41.	97.	450000	7	5.0		c	3
3		1879			39.6	99.1		4- 5	4.0		d	4
12	29	1879	6	30	42.9	97.3		5	3.6		e	3
12	28	1880	7	15	49.0	97.2		3- 4	3.6		d	4
3	17	1884	20		41.1	100.7		4	3.8		d	4
10	11	1895	23	55	43.9	103.3	4000	5	3.8		c	3
10	12	1895	1	25	43.9	103.3	4000	5	3.8		c	3
2	4	1896	11	45	42.6	97.3		3	3.4		d	4
9	16	1898	9	59	42.6	97.3		4	3.8		d	4
12	6	1899	12		44.5	99.0	10000	4	4.0		c	4
7	28	1902	18		42.5	97.5	90000	5- 6	4.5		c	3
12	1	1904	9		41.8	96.7		3	3.4		d	4
1	8	1906	0	15	39.2	96.5	95000	7- 8	4.9		b	5
1	8	1906	0	38	39.2	96.5		2	3.0		d	5
1	8	1906	4	30	39.2	96.5		2	3.0		d	5
1	8	1906	7		39.2	96.5		2- 3	3.2		d	5
1	8	1906	8		39.2	96.5		2- 3	3.2		d	5
1	14	1906	15		39.2	96.5		2- 3	3.2		d	5
1	16	1906	2	40	39.2	96.5	40000	4	4.1		c	5
1	20	1906	5	30	39.2	96.5		3	3.4		d	5
1	23	1906	13	40	39.2	96.5		3	3.4		d	5
1	23	1906	14	25	39.2	96.5		3	3.4		d	5
5	10	1906	0	27	43.0	101.3	45000	6	4.7		d	3
1	26	1909	20	15	42.3	97.8	2500	4- 5	3.6		c	4
2	26	1910	8		41.4	97.4		4- 5	3.8		e	3
6	2	1911	22	34	44.2	98.2	100000	5	4.5		c	3
8	8	1915	15	15	48.1	103.6		4	3.8		d	4
9	16	1915	19		42.8	99.3		3- 4	3.6		d	4
10	23	1915	6	5	43.8	101.5		5	3.8		e	3
2	24	1916	4	30	43.0	102.5		3	3.4		d	4
6	29	1916	7	45	43.4	99.9		3	3.4		d	4
12		1916			41.5	100.5		2- 3	3.2		d	4
2	6	1917	17	26	47.9	95.0		4	3.8		d	4
9	3	1917	21	30	46.3	94.8	48000	6	4.3		c	3
7	14	1920	23		43.2	103.2	4000	3	3.7		c	4
3	16	1921	23	45	43.5	96.7		3- 4	3.6		d	4
9	24	1921	0	30	43.7	98.7		4	3.8		d	4

LIST OF EARTHQUAKES IN THE AREA WITH VERTICES
49N, 105W; 49N, 94W; 39N, 105W; 39N, 94W. (cont)

DATE			TIME			LAT	LONG	FELT AREA	INT	mb	MS	SYM	REF
1	2	1922	14	50		43.8	99.3		6	4.7		d	4
9	10	1923	6	30		41.7	96.2		3- 4	3.6		d	4
9	24	1924	11			40.9	100.1		4	3.8		d	4
12	30	1924	22	10		43.5	103.5	18000	4	4.0		c	4
8	25	1925	6	27		42.8	97.4		4	3.8		d	4
3	18	1927	17	25		39.9	95.3	800	6	3.9		e	5
4	30	1927	4	15		46.9	102.1		2	3.0		d	4
10	14	1927	16	10		41.6	98.9	1000	4	3.5		c	4
11	16	1928	13	45		44.1	103.7	5000	5	3.7		c	3
9	23	1929	10			39.0	96.6		5	4.0		d	5
9	23	1929	11			39.0	96.6	40000	5	4.2		c	5
10	6	1929	12	30		42.8	97.4	1800	5	3.5		c	4
10	21	1929	21	30		39.2	96.5	20000	5	4.0		c	5
10	23	1929				39.0	96.8		2- 3	3.2		d	5
12	7	1929	8	2		39.2	96.6	2500	5	3.6		c	5
1	17	1931	18	45		43.7	98.7		4	3.8		d	4
8	9	1931	6	18	37	39.1	94.7	800	6	3.8		e	5
8	9	1931	7	7		39.1	94.7		3	3.0		d	5
8	9	1931	7	15		39.1	94.7		3	3.0		d	5
1	29	1932	0	15		39.0	99.6	5000	6	3.8		e	5
2	20	1933	17			39.8	99.9	15000	5- 6	4.0		c	5
8	8	1933				41.9	103.7		4- 5	4.0		d	4
1	29	1934	12	30		45.9	97.7		4	4.2		d	4
5	11	1934	10	40		41.5	98.7	2500	4	3.6		c	4
7	30	1934	7	20		42.2	103.0	60000	6	4.3		c	4
8	30	1934	3	50		43.4	99.1		4	3.6		d	4
11	8	1934	4	45		42.6	100.2	3000	3	3.6		c	4
1	30	1935	22			40.5	94.0		3	3.4		d	4
3	1	1935	10	59	44	40.3	96.2	210000	7	4.7	3.0	c	3
3	1	1935	11	4		40.3	96.2		2	3.0		d	4
3	22	1935	22	45		40.3	96.1		4	3.8		d	4
11	1	1935	10			44.0	96.6		3	3.4		d	4
10	30	1936	10	30		43.5	103.5		4	3.8		d	4
1	2	1938	17	5		44.5	98.2	8000	4- 5	3.9		c	4
3	24	1938	13	11		42.7	103.4	5000	4	3.7		c	4
10	1	1938	22	15		43.8	99.3	23000	5	4.2		c	4
10	11	1938	9	37		43.5	96.7	20000	5	4.1		c	4
11	4	1938	22	10		43.2	98.9	5000	4	3.8		c	4
1	28	1939	17	55		46.8	95.8	20000	4	4.1		c	4
6	10	1939	18	30		43.0	98.9		4	3.8		d	4
5	25	1941	6	25		43.5	103.5	20000	4- 5	4.1		c	4
3	11	1942	16	55		44.4	103.5		3- 4	3.6		d	4
5	16	1943	19	40		43.5	103.5		4	3.8		d	4
11	10	1945	8			43.0	97.9		4	3.8		d	4
7	23	1946	6	45		44.1	98.6	22000	6	4.2		c	3

LIST OF EARTHQUAKES IN THE AREA WITH VERTICES
49N, 105W; 49N, 94W; 39N, 105W; 39N, 94W. (cont)

DATE			TIME			LAT	LONG	FELT AREA	INT	mb	MS	SYM	REF
10	26	1946	20	37		48.1	103.6		4	3.8		d	4
5	14	1947	5	2		46.0	100.9		4	3.8		d	4
5	16	1947	5	45		44.4	100.3		3- 4	3.6		d	4
8	25	1947	14			43.1	98.9		4	3.8		d	4
4	7	1948				41.4	99.6		2- 3	3.2		d	4
5	7	1949	14	54	10	44.5	99.0		3	3.4		d	4
5	13	1949	4	15		42.5	99.0	3000	4	3.6		c	4
6	3	1949				45.	100.		4	3.8		d	4
12	14	1949	3	15		43.2	99.4		3	3.4		d	4
2	15	1950	10	5		46.1	95.2	3000	4- 5	3.6		c	4
11	15	1952				44.1	103.5		4	3.8		d	4
12	21	1953	22	43		45.2	102.9		3- 4	3.6		d	4
12	31	1953	20	30		43.1	99.3		4	3.8		d	4
2	25	1955	1	45		41.3	98.6	3000	4	3.6		c	4
12	3	1957	7	30		43.8	98.2	250	4	3.2		c	4
1	12	1959	13			44.9	98.1		4	3.8		d	4
4	13	1961	21	14	57	39.9	100.0	6500	5	3.8		c	5
12	25	1961	12	20	3	39.1	94.6	20000	4	3.9		c	5
12	25	1961	12	58	21	39.1	94.6	26000	5	4.1		c	5
12	31	1961	16	35	59	44.4	100.3	34000	5- 6	4.3		c	4
3	9	1963	15	25		42.8	103.0		2- 3	3.2		d	4
3	24	1964	6	12		43.5	103.5	4000	5	3.7		c	3
3	28	1964	10	8	45	42.8	101.7	270000	7	4.7		a	3
3	28	1964	10	24	50	42.8	101.7			3.6		a	28
8	26	1964	16	58	52	43.8	102.2		4	3.8		d	4
9	28	1964	15	41		44.0	96.4			3.4		a	28
6	26	1966	11	59	44	44.3	103.4	3000	6	3.1		ae	3
9	9	1966	9	50	31	41.4	98.6			3.5		a	12
11	23	1967	6	23	39	43.7	99.4		5	3.8		a	3
7	8	1968	16	50	12	46.5	100.6	25000	4	4.4		a	24
10	19	1971	21	7	31	44.0	101.0			3.0		a	12
10	16	1972	5	47	33	42.3	99.6			3.7		a	12
5	13	1975	7	53	38	42.1	98.4		6	3.5		a	24
5	16	1975	5	57	1	43.2	103.7		4	3.8		d	24
7	9	1975	14	54	15	45.5	96.1	82000	6	4.8		a	24

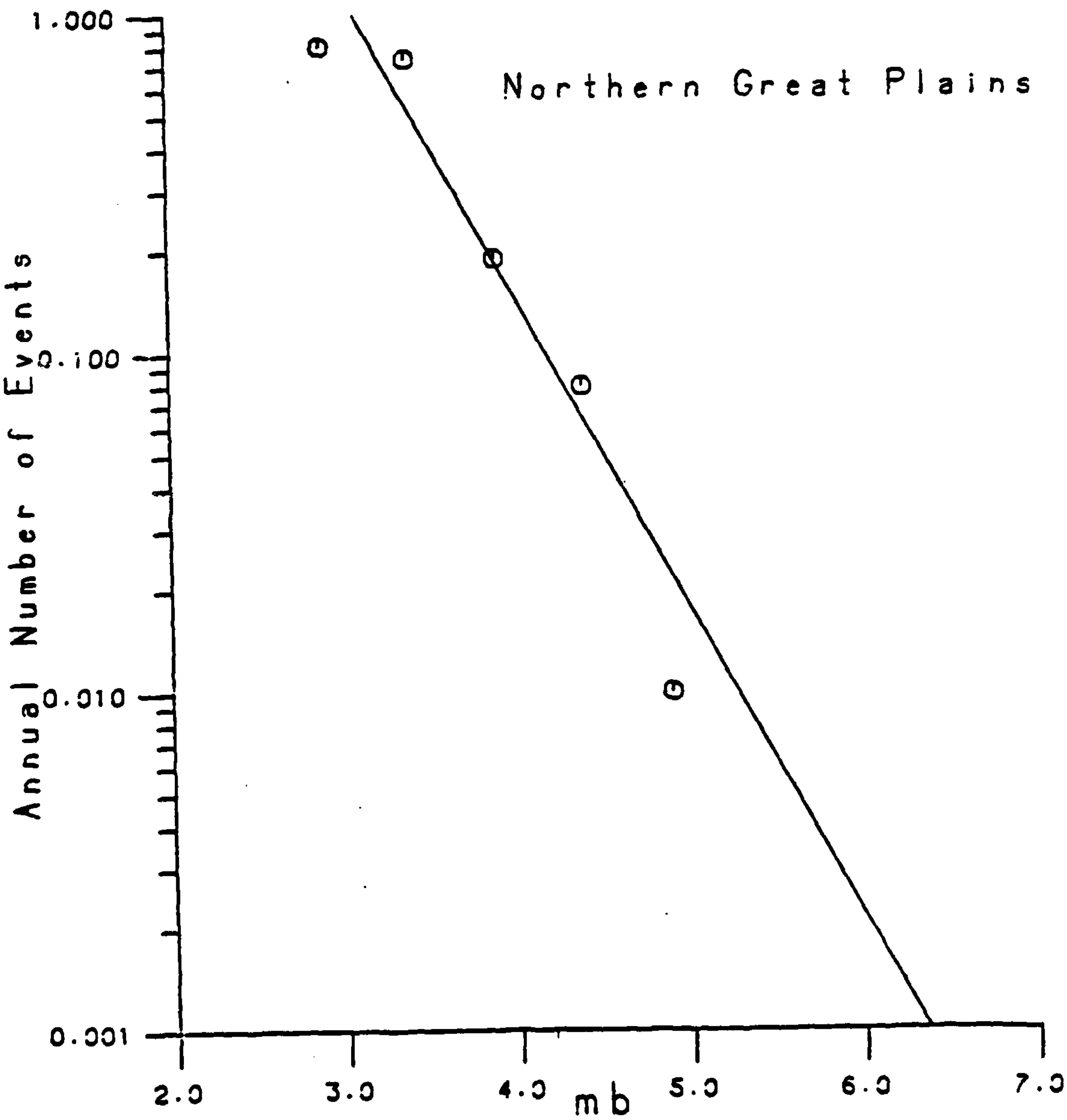


Figure 8. N_c vs m_{bLg} for Northern Great Plains source zone.

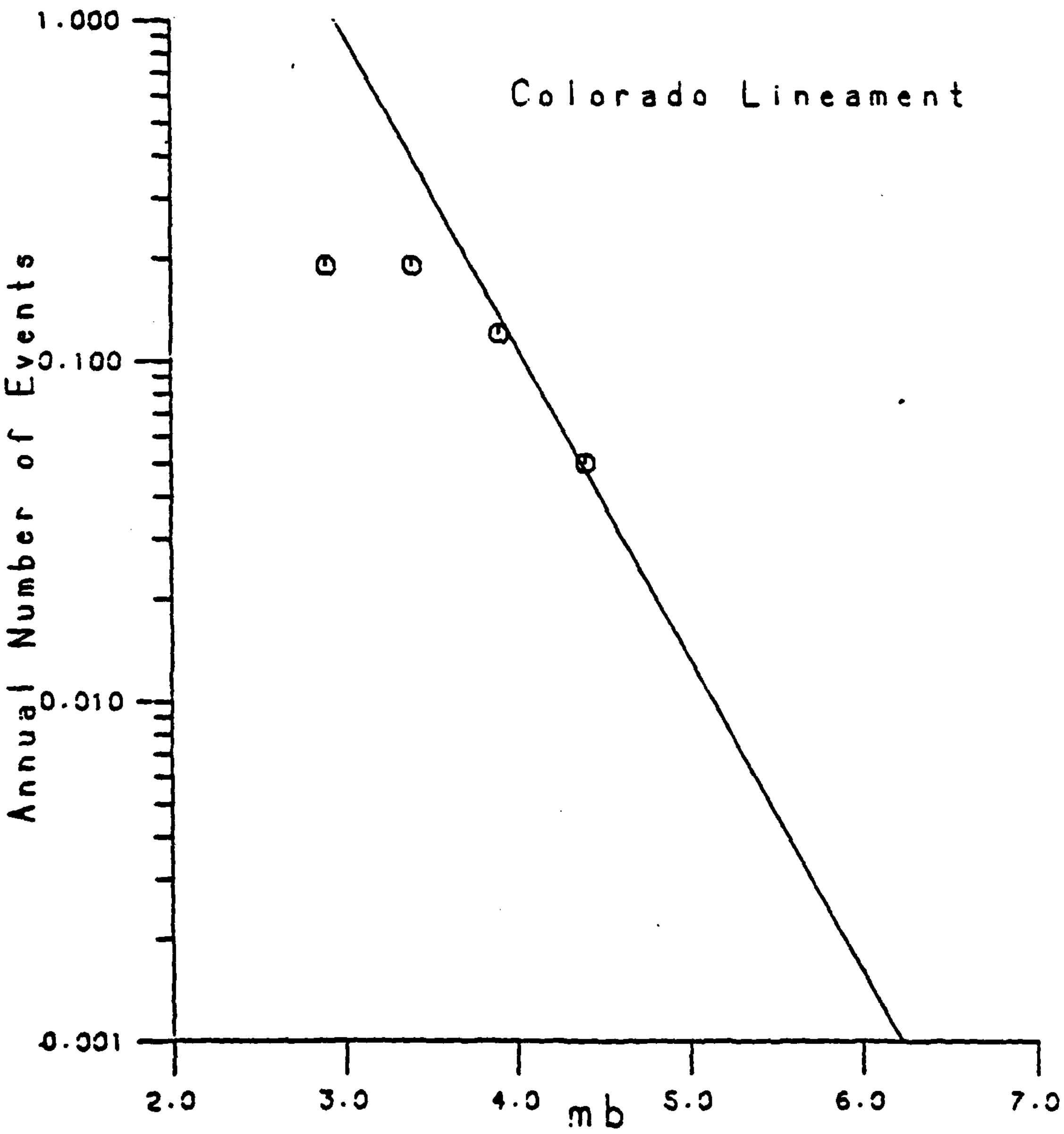
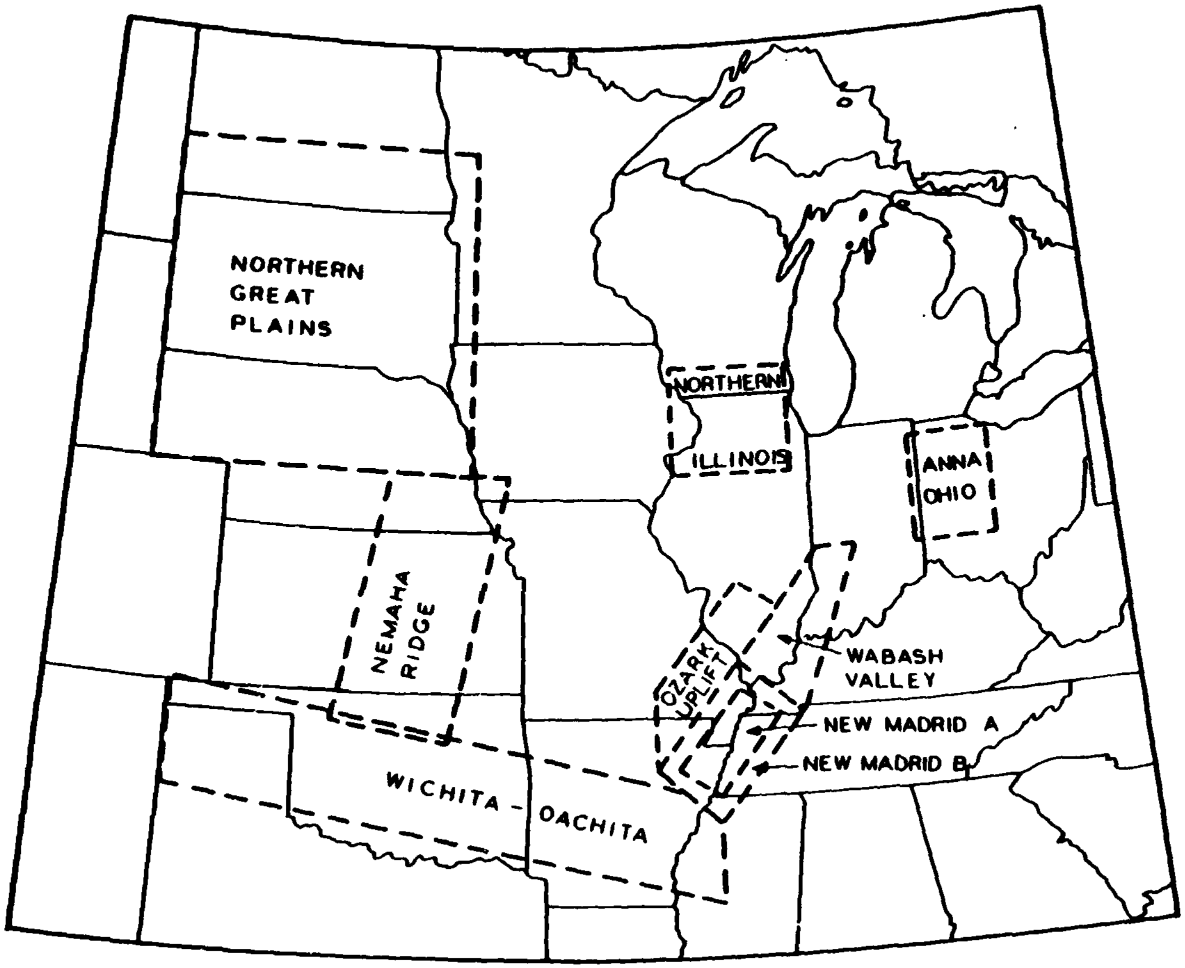
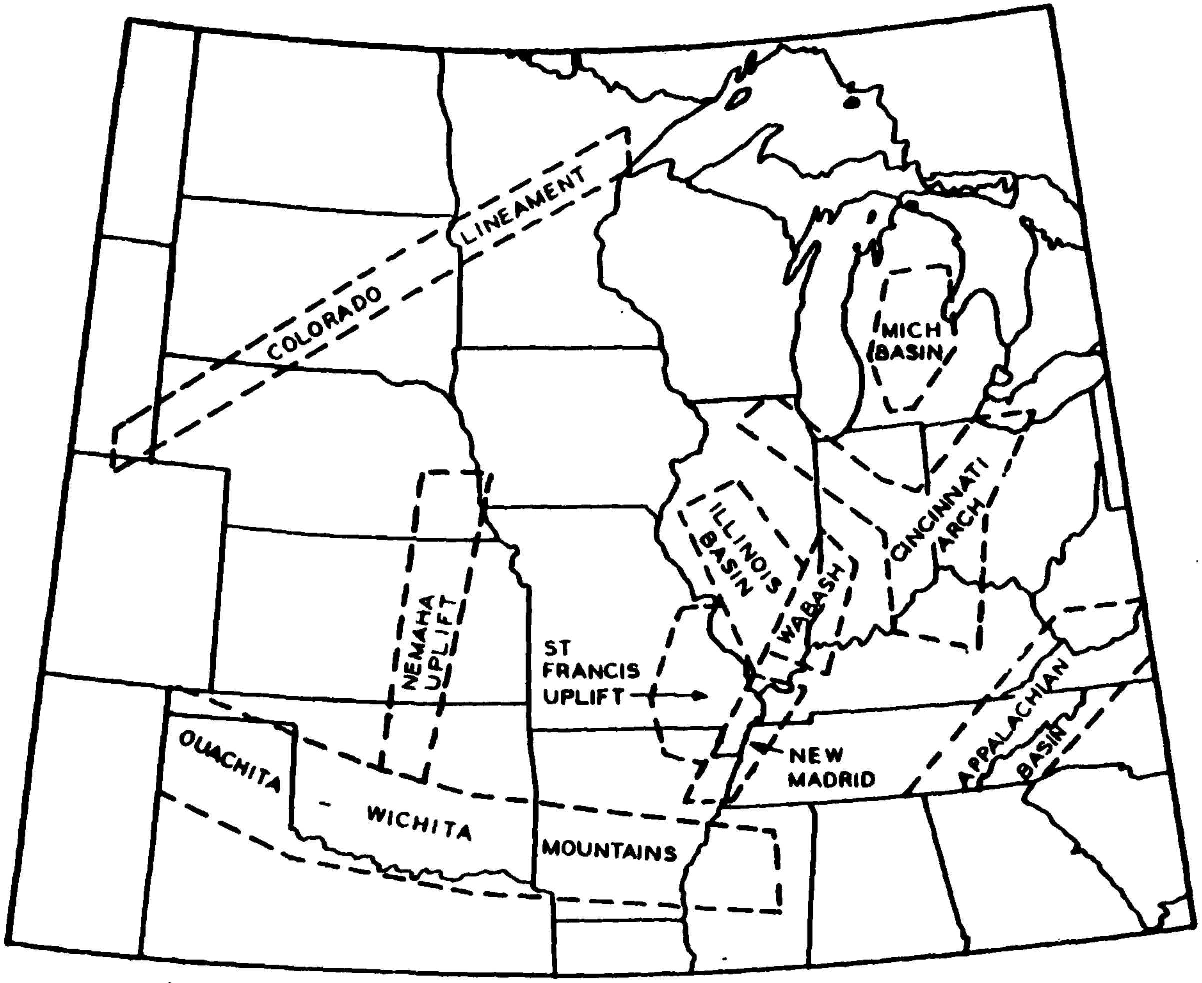


Figure 24. N_c vs m_b for Colorado Lineament source zone.



Nuttli-Herrmann (1979) source zones.



Nuttli-Brill (1980) source zones.

APPENDIX B

This appendix contains 15 selected high altitude NASA photographs with clear overlays depicting lineaments. All are false-color infrared taken with a 9 inch source. Healthy vegetation appears red in these photos, water appears black or dark blue, and snow appears white. The scene center point listed in the following table is determined from the indicators on the edges of the photos. The left edge of each photograph is cut to fit this format, although the full photograph was used in the investigations. These are the primary photographs used in the field investigation.

PHOTO NO. 2443. Scale 1: 127,000
Center Point N 44D04M45S W101D01M15S

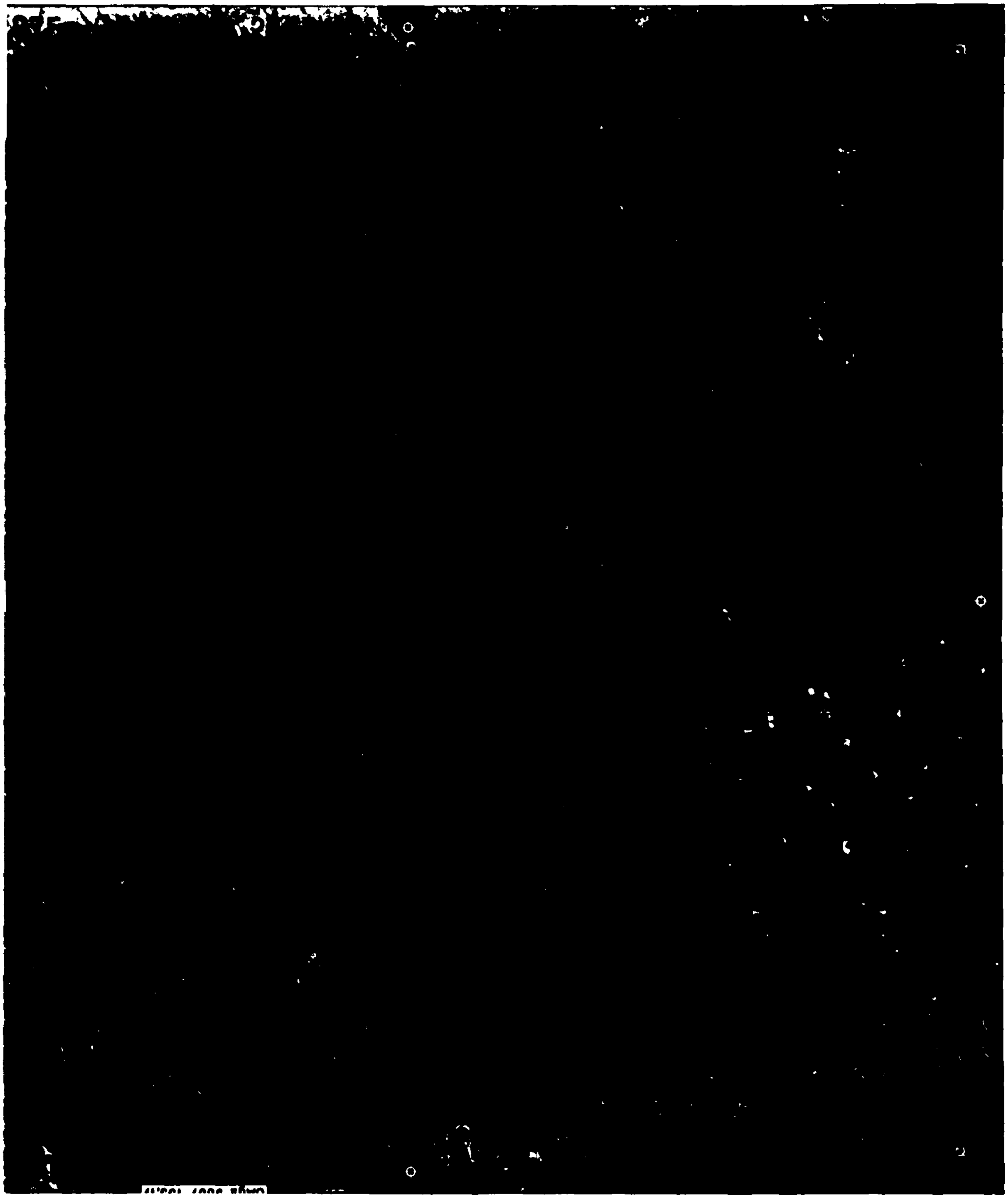


PHOTO NO. 2445. Scale 1: 128,000
Center Point N 44D13M45S W101D00M30S

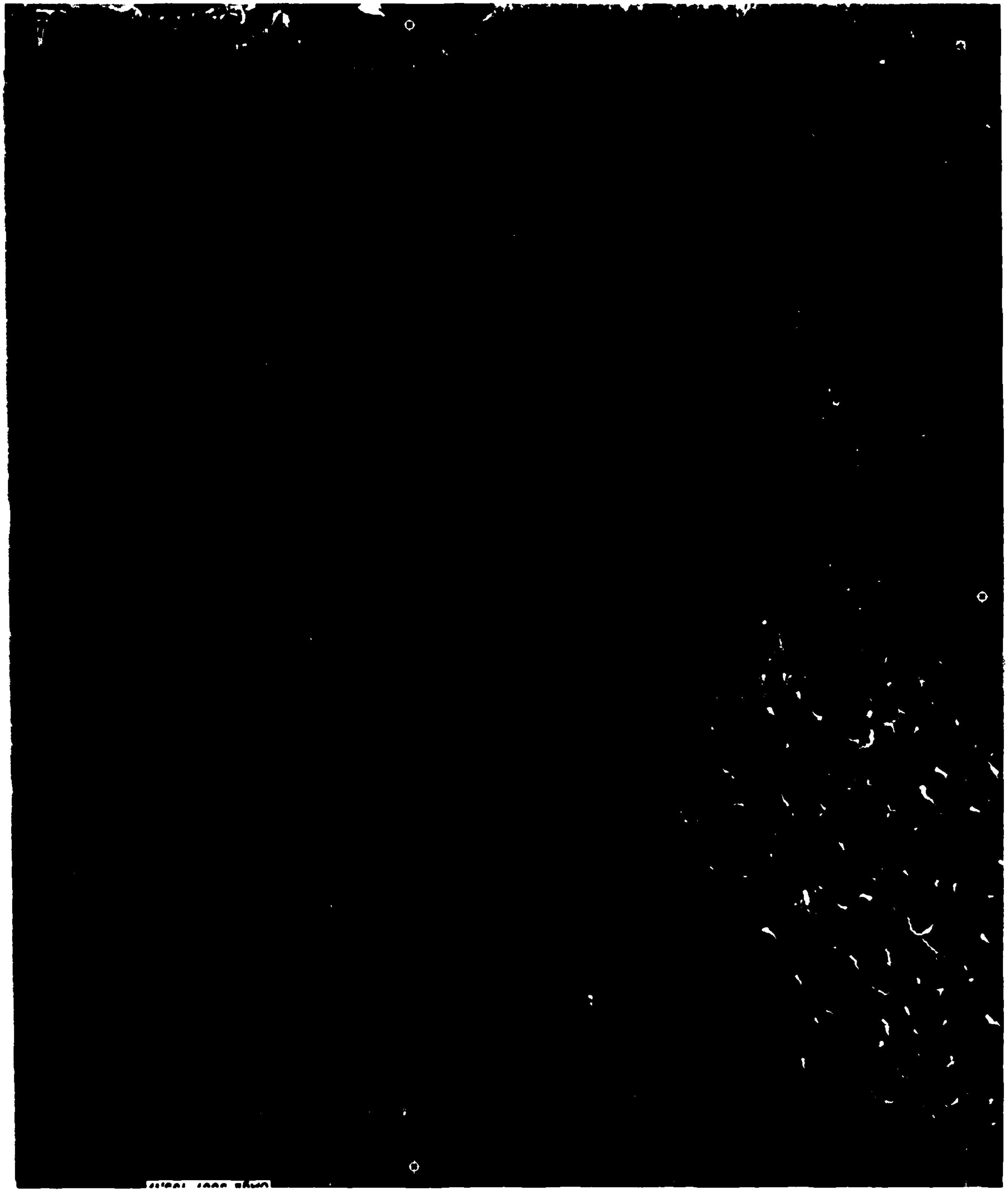


PHOTO NO. 2449. Scale 1: 126,000
Center Point N 44D36M15S W101D01M00S

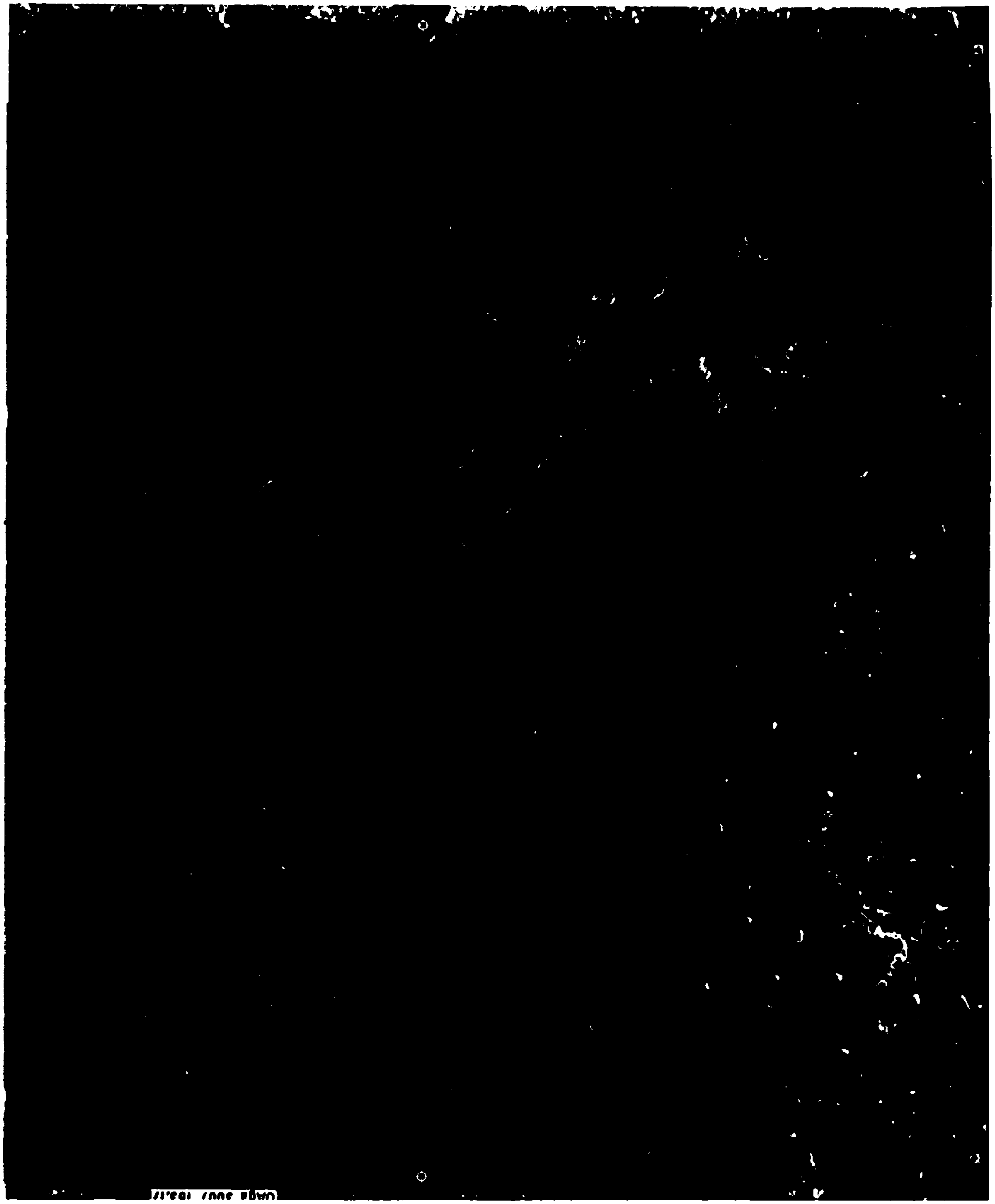


PHOTO NO. 2450.　　Scale 1: 126,000
Center Point N44D42M45S　　W101D01M30S

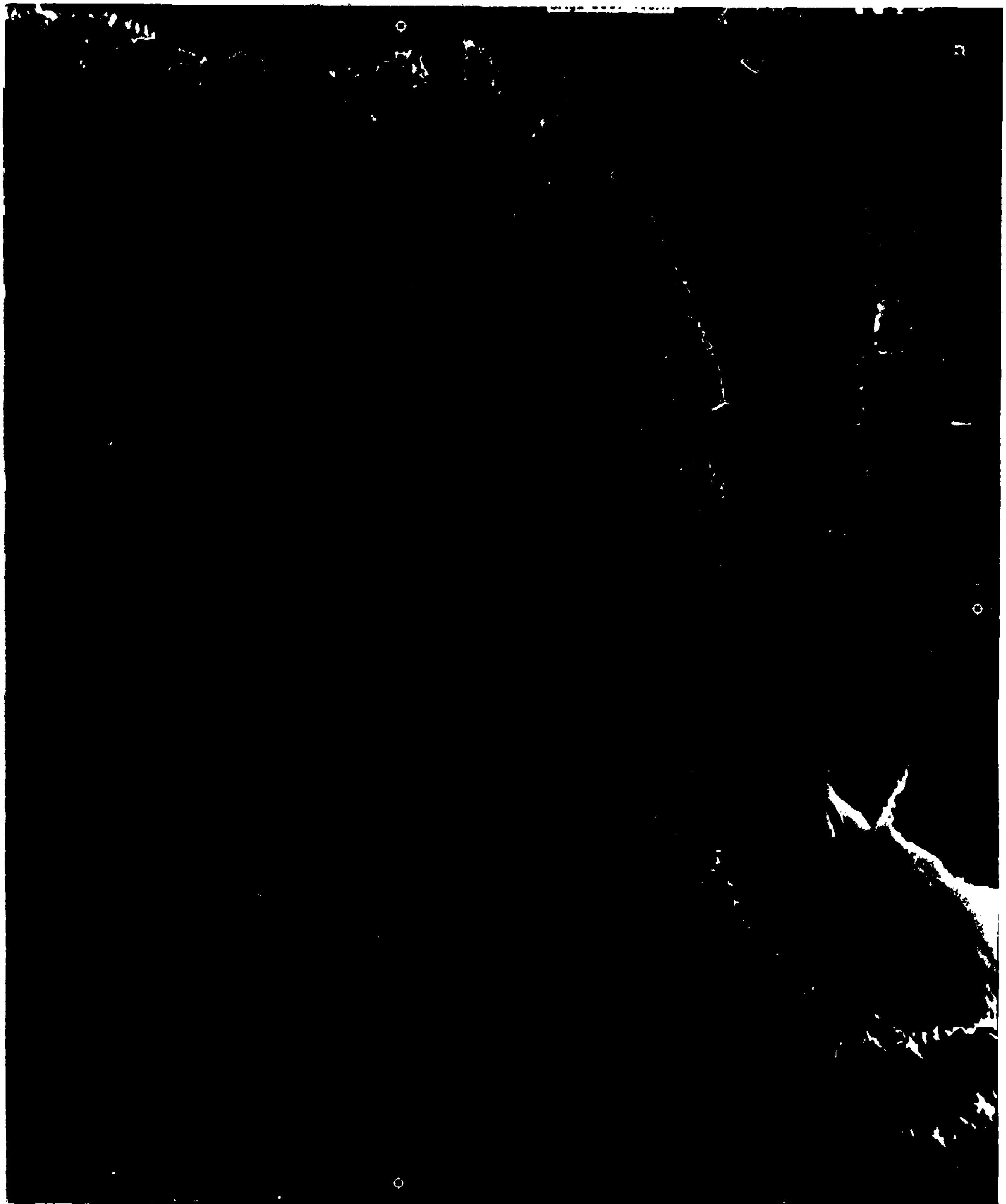


PHOTO NO. 2455. Scale 1: 129,000
Center Point N44D38M30S W100D45M00S

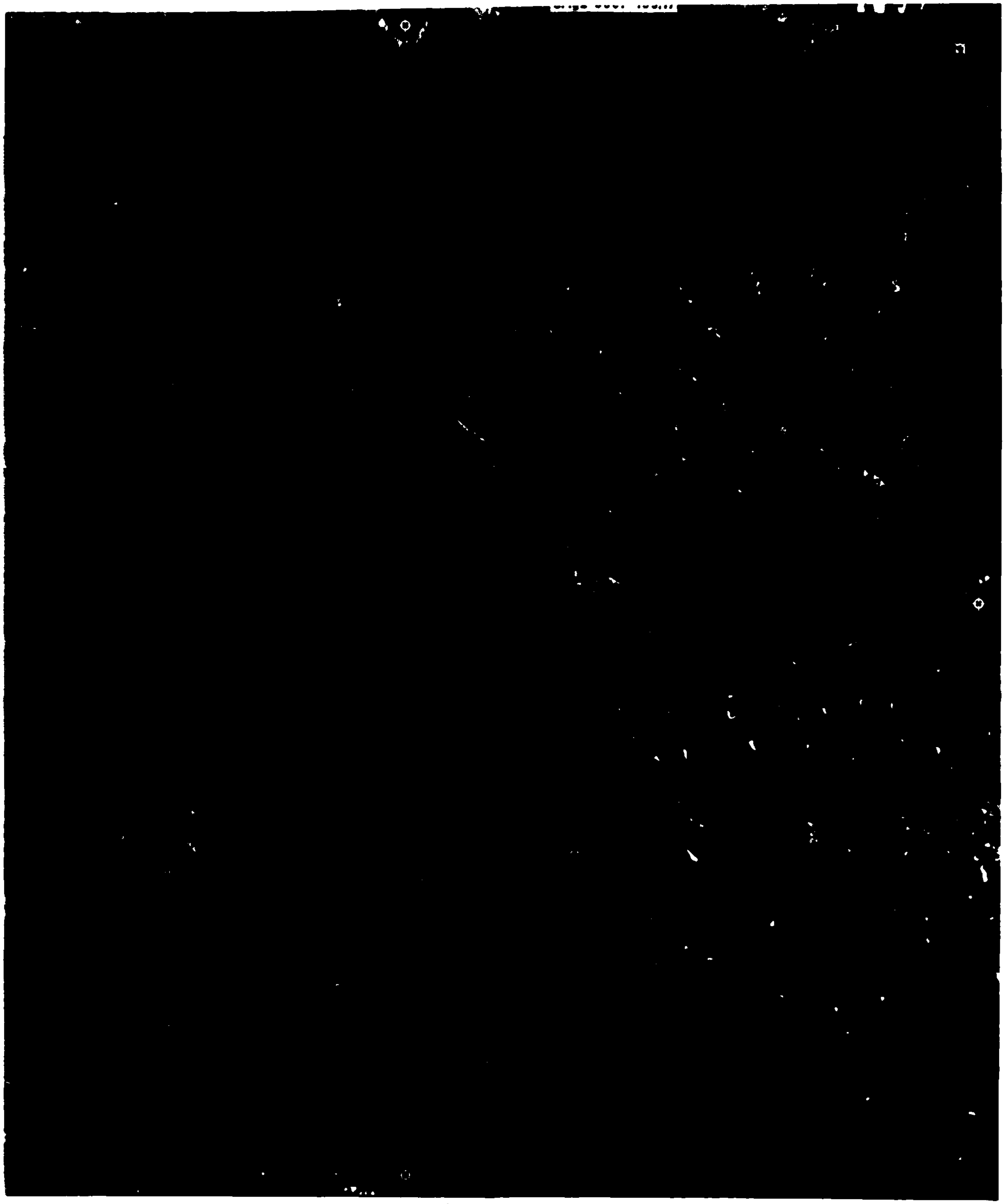


PHOTO NO. 2457. Scale 1:129,000
Center Point N44D25M45S W100D45M00S

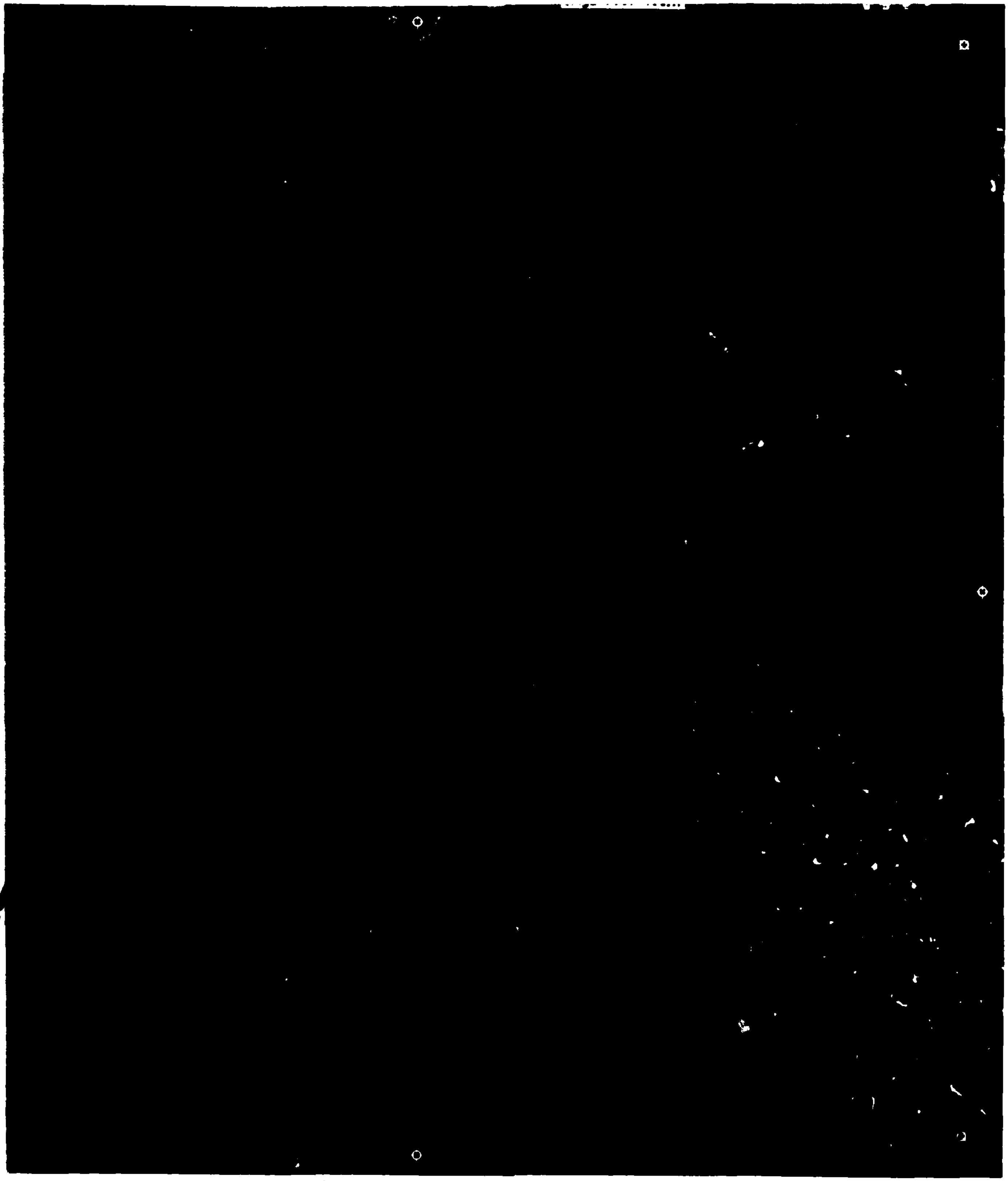


PHOTO NO. 2459. Scale 1: 129,000
Center Point N44D12M45S W100D46M00S

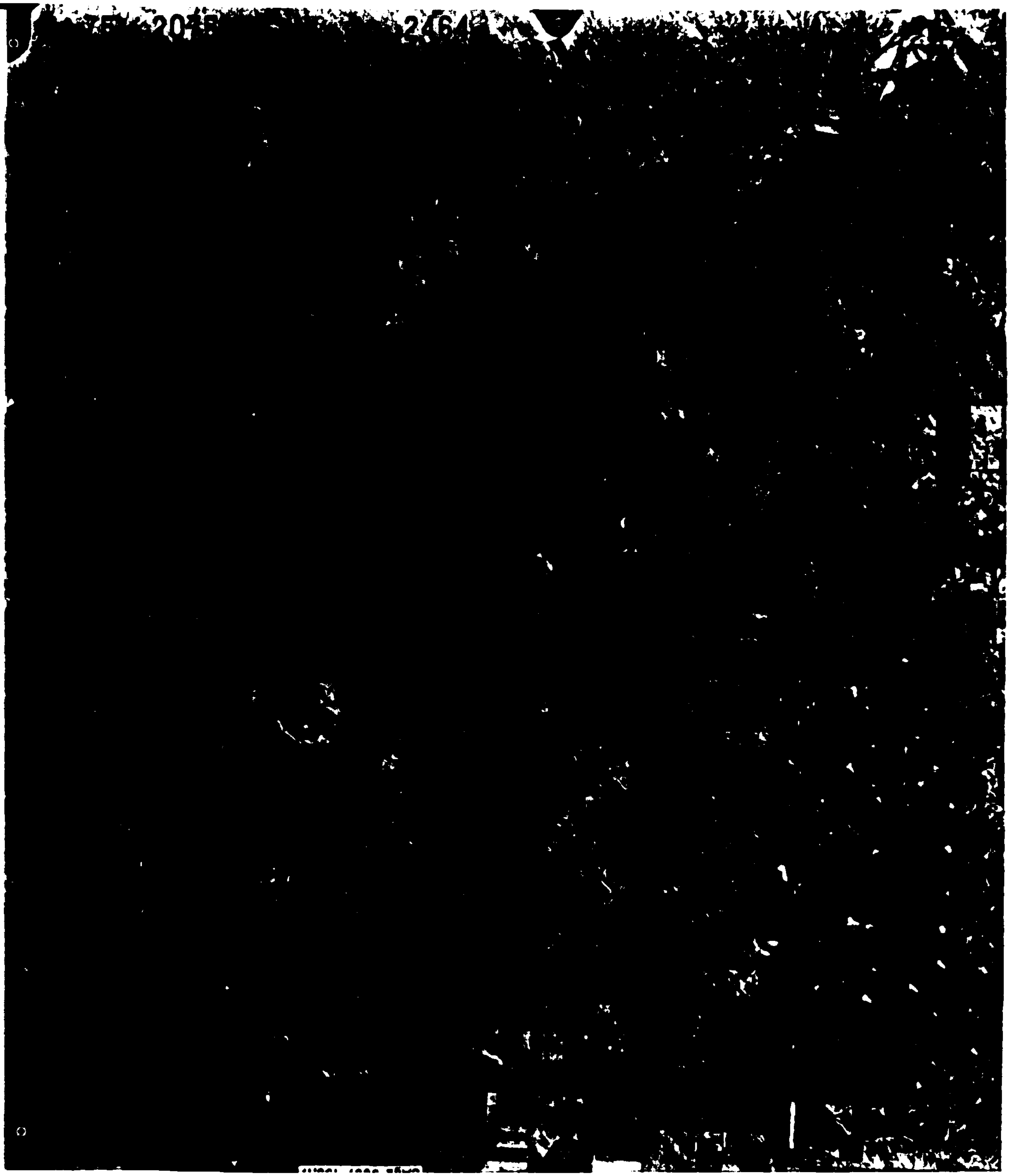


PHOTO NO. 2464. Scale 1: 124, 000
Center Point N44D16M00S W100D28M54S

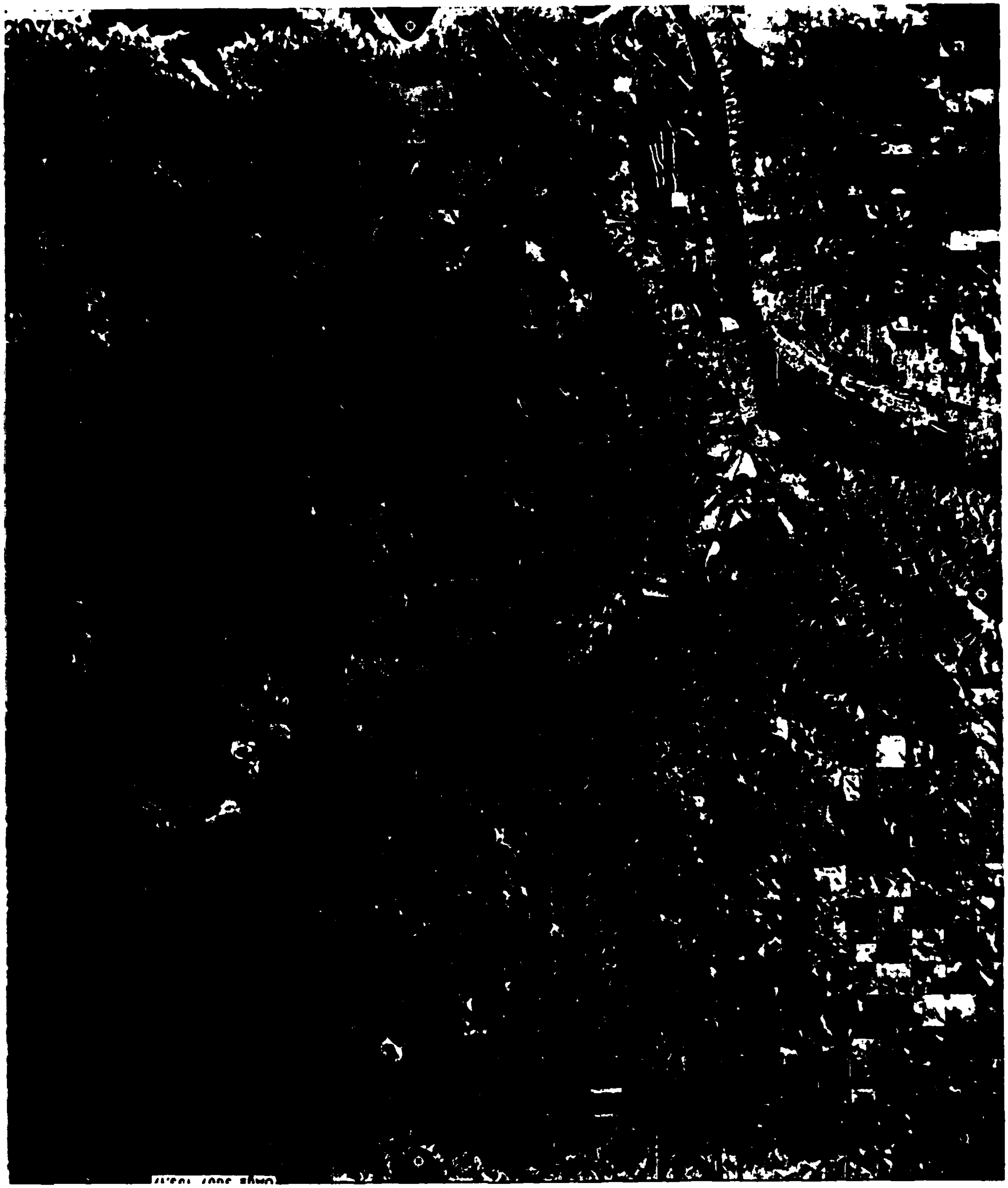


PHOTO NO. 2465. Scale 1: 124,000
Center Point N44D19M00S W100D28M30S

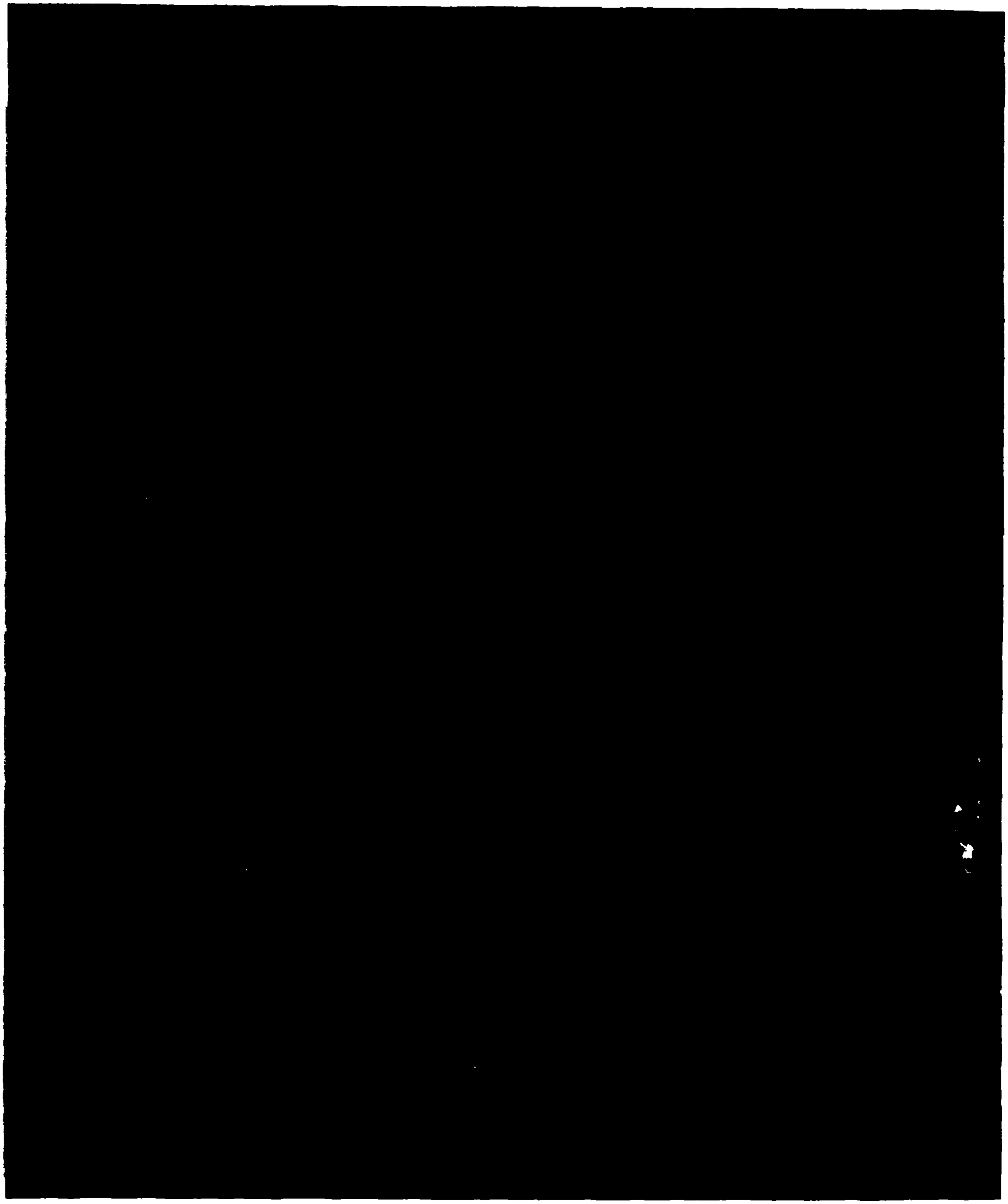


PHOTO NO. 4553. Scale 1: 130,000
Center Point N44D44M00S W101D08M15S

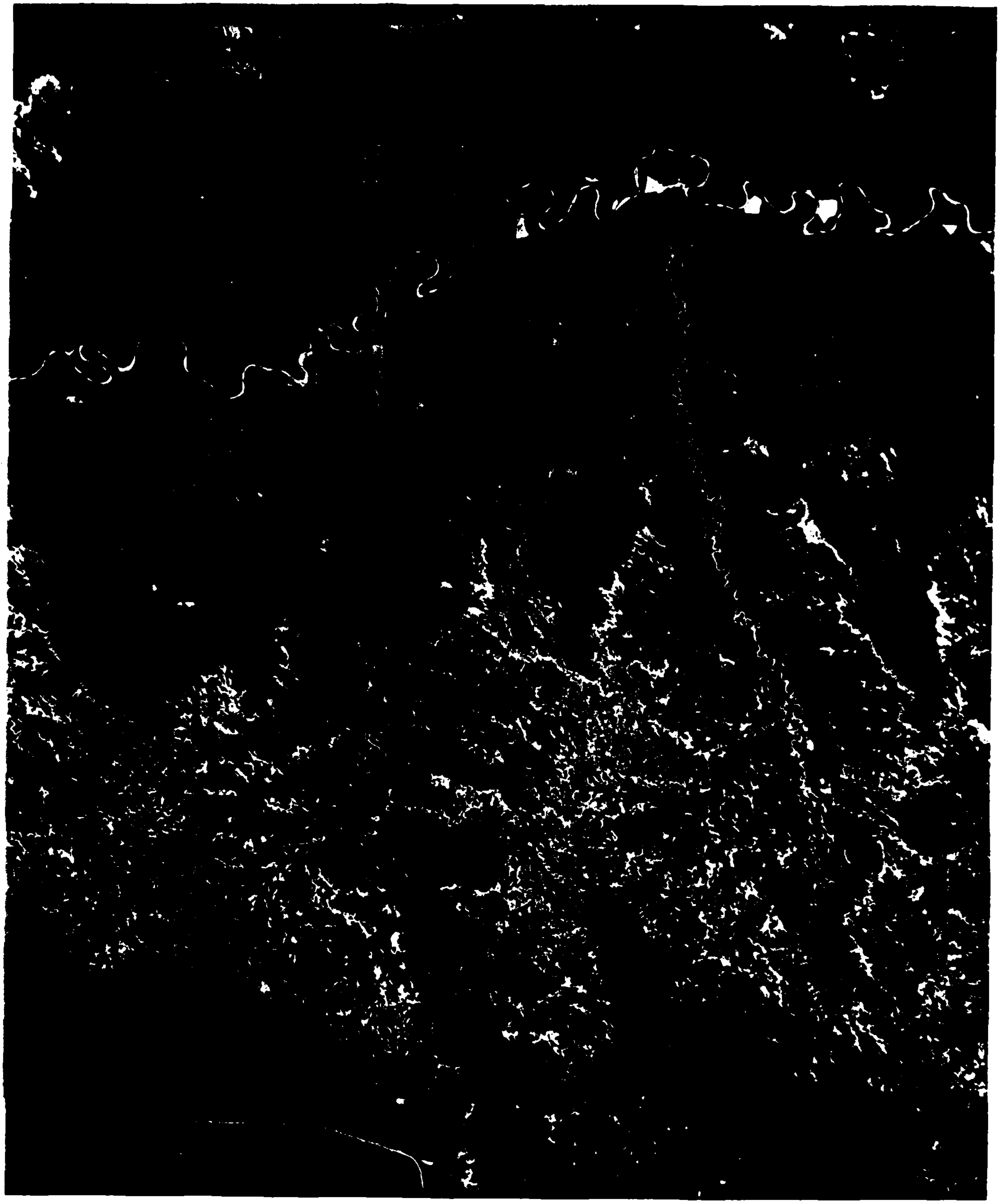


PHOTO NO. 8612. Scale 1: 126,000
Center Point N43D44M00S W101D24M30S

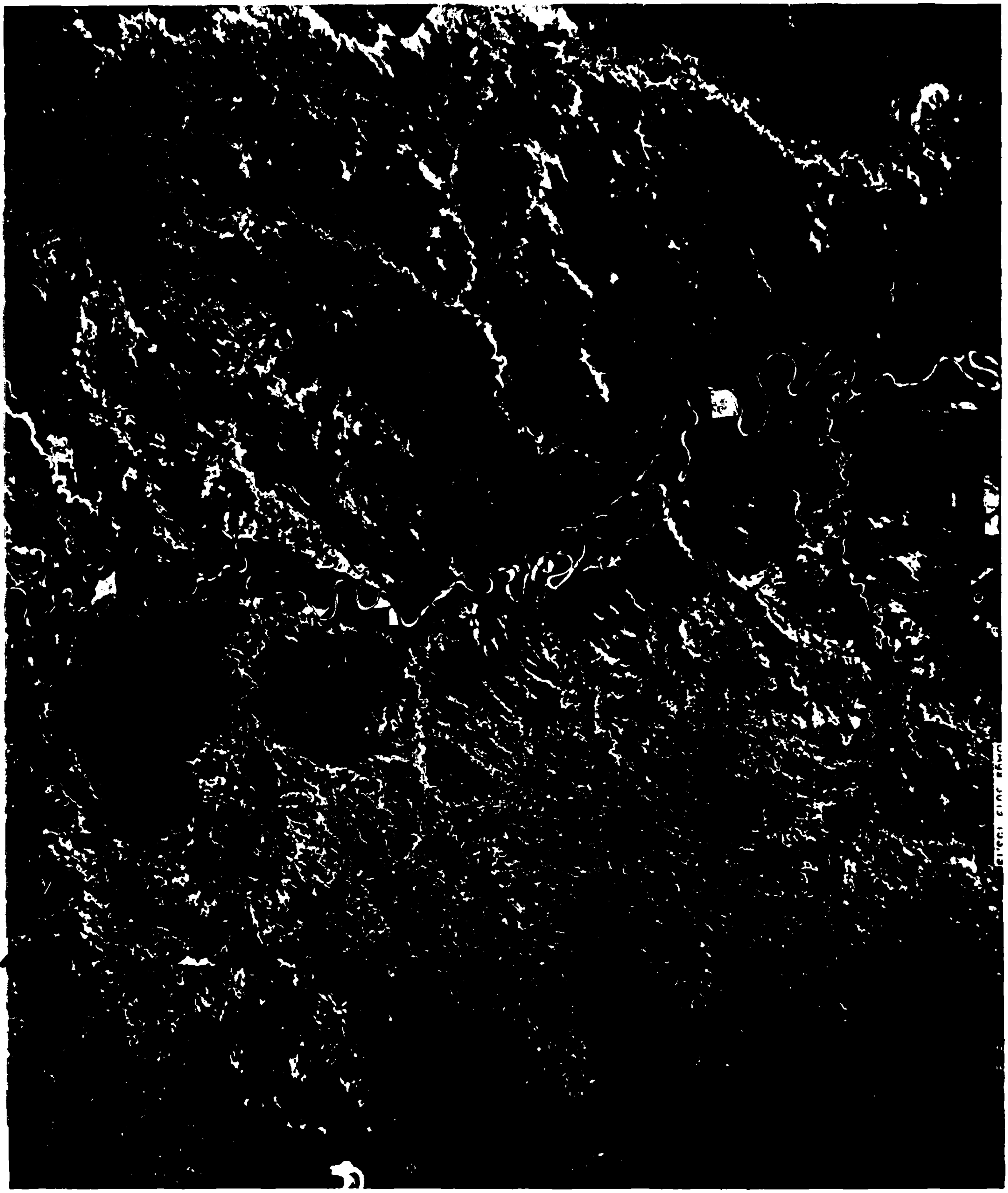


PHOTO NO. 8614. Scale 1: 127,000
Center Point N43D42M00S W101D43M45S

PHOTO NO. 8616. Scale 1: 127,000
Center Point N43D42M15S W102D02M30S

PHOTO NO. 8648. Scale 1: 126,307
Center Point N43D52M30S W101D42M30S

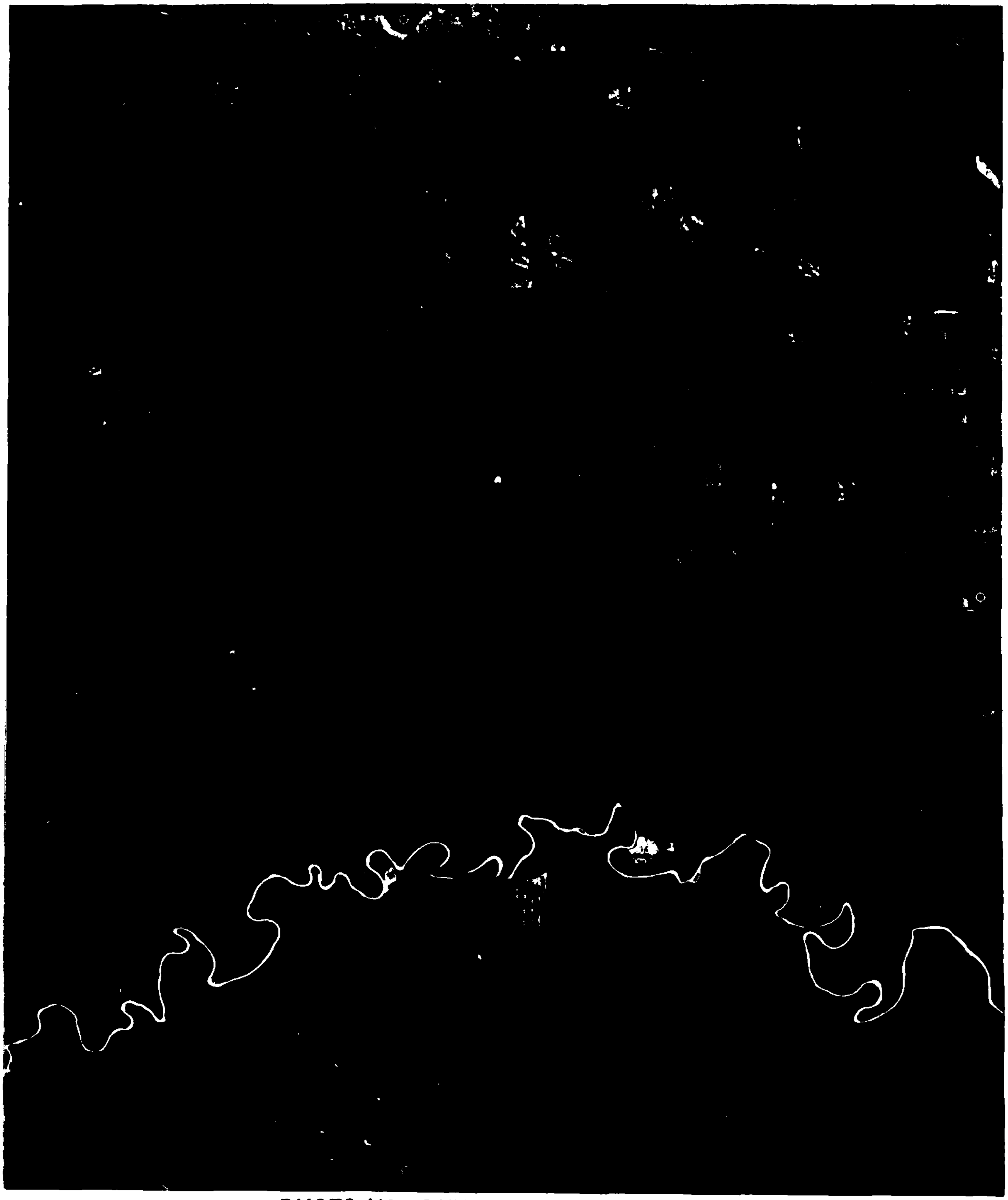


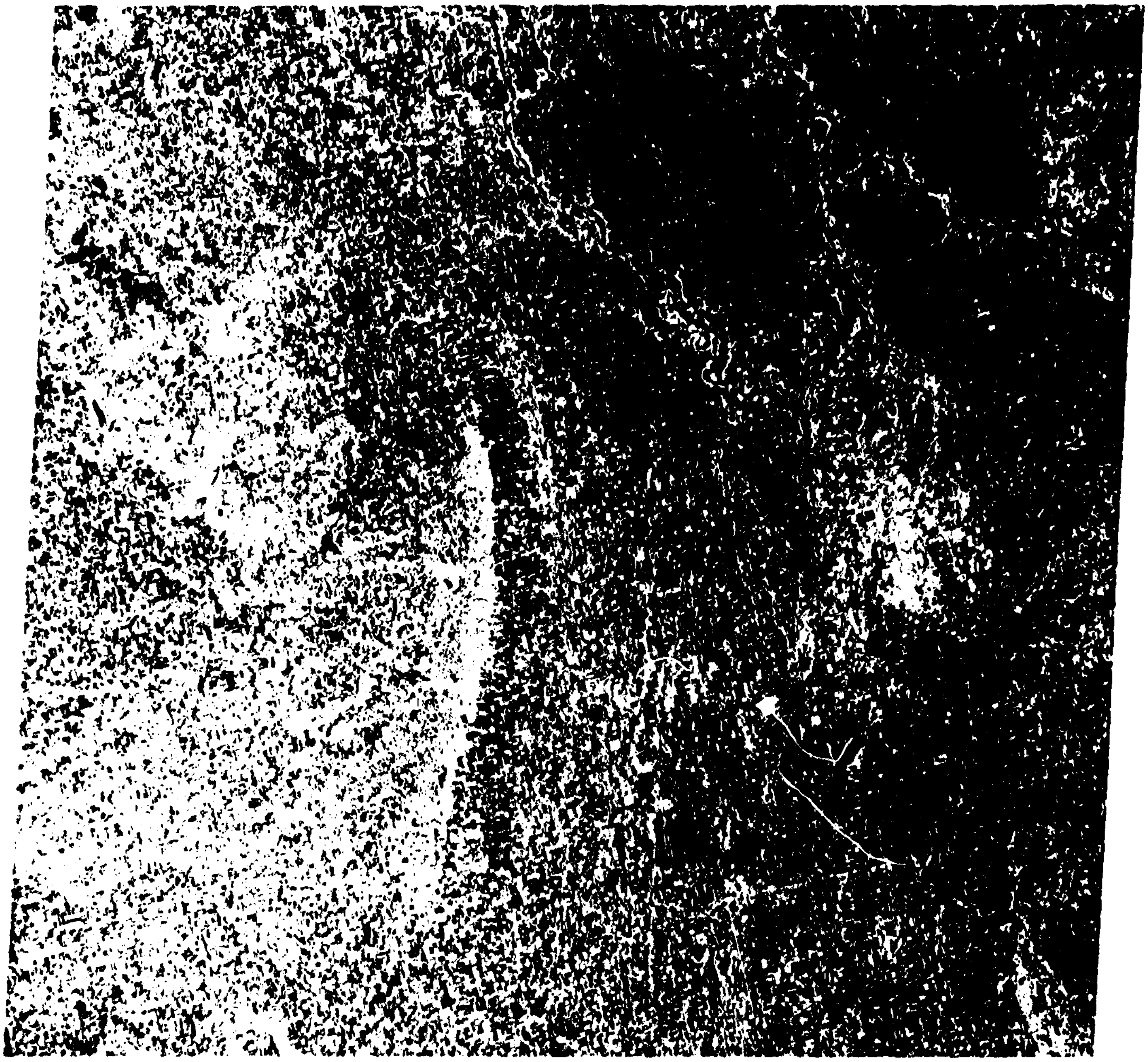
PHOTO NO. 8652. Scale 1: 127,625
Center Point N43D54M18S W101D05M36S

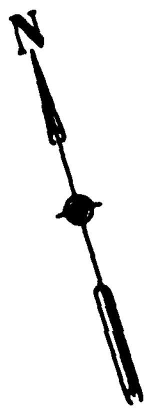
APPENDIX C

Following are the nine Landsat scenes covering the study area. The scale for these false-color imagery scenes is 1:1,000,000. Larger copies of the same scenes were used to locate smaller features, although some linear features may be visible in this scale.

Table 1

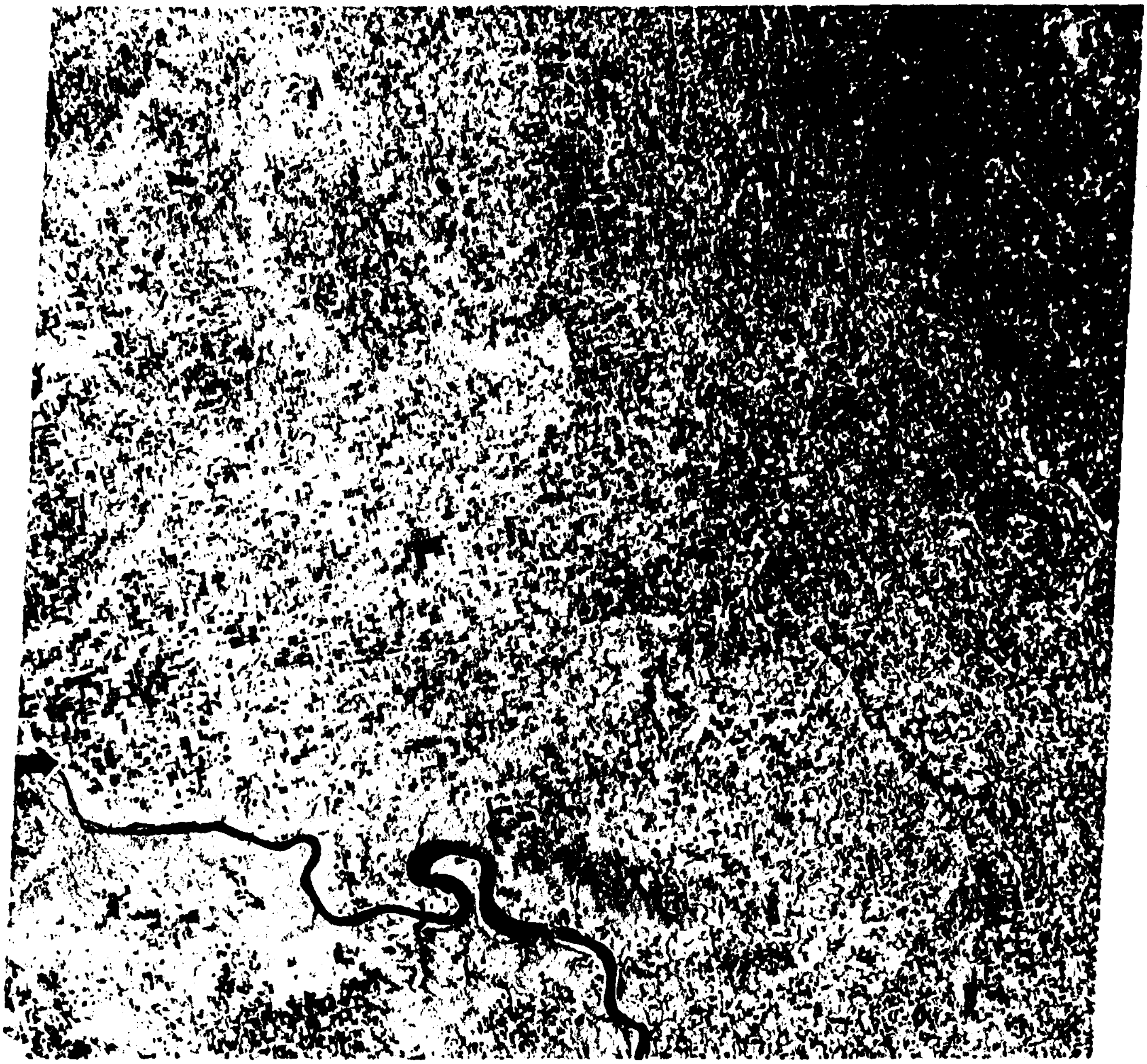
Photograph Number	Scale	Center Point	
2443	1:127,000	N44D04M45S	W101D01M15S
2445	1:128,000	N44D13M45S	W101D00M30S
2449	1:126,000	N44D36M15S	W101D01M00S
2450	1:126,000	N44D42M45S	W101D01M30S
2455	1:129,000	N44D38M30S	W100D45M00S
2457	1:129,000	N44D25M45S	W100D45M00S
2459	1:129,000	N44D12M45S	W100D46M00S
2464	1:124,000	N44D16M00S	W100D28M54S
2465	1:124,000	N44D19M00S	W100D28M30S
4553	1:130,000	N44D44M00S	W101D08M15S
8612	1:126,000	N43D44M00S	W101D24M30S
8614	1:127,000	N43D42M00S	W101D43M45S
8616	1:127,000	N43D42M15S	W102D02M30S
8648	1:126,307	N43D52M30S	W101D42M30S
8652	1:127,625	N43D54M18S	W101D05M36S





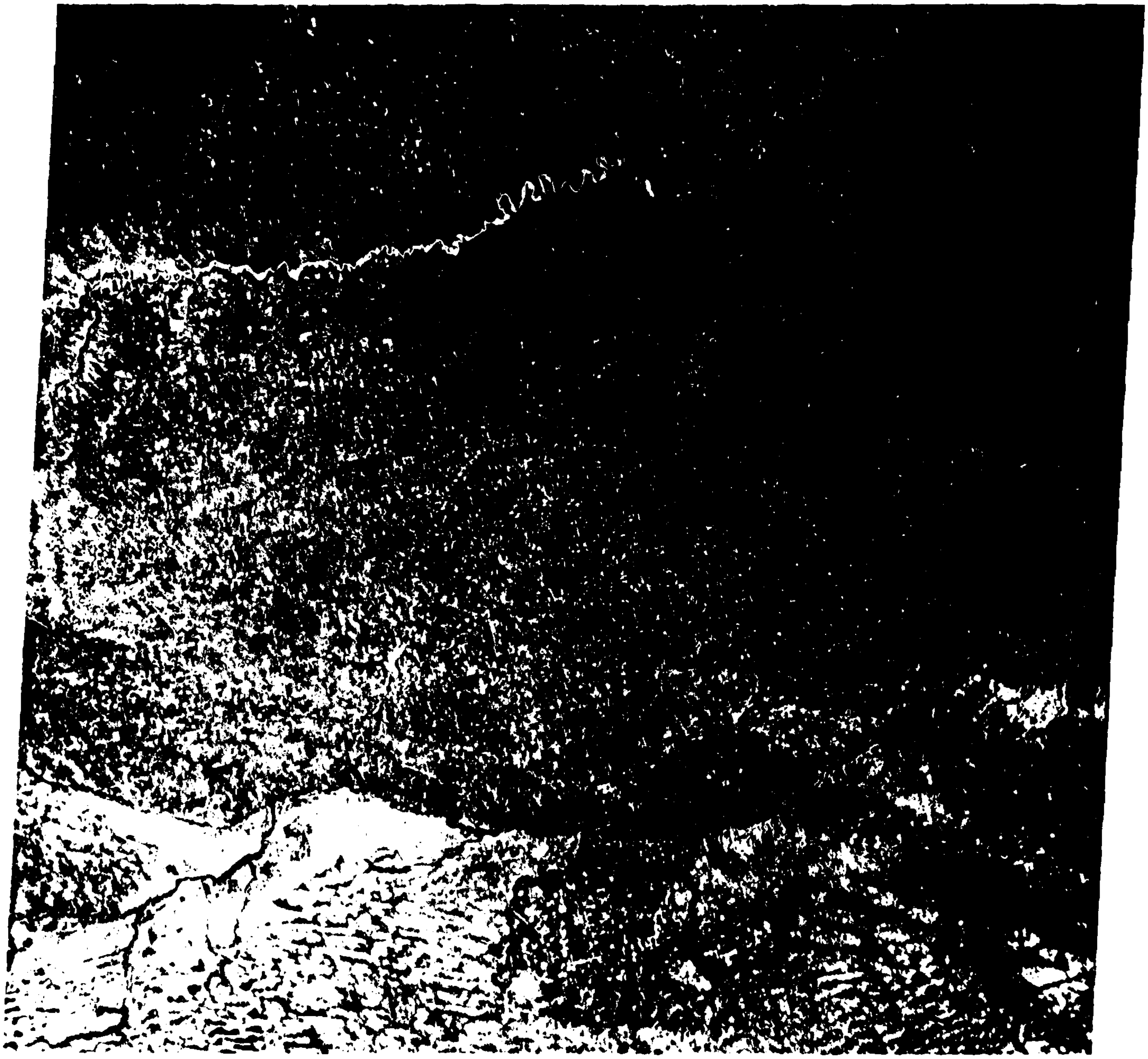
LANDSAT IMAGERY

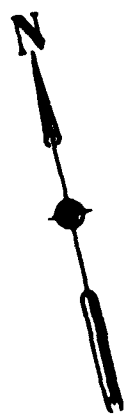
SCENE: 033-028
CENTER POINT: N 46D 03M/W 98D 39M
SCALE: 1:1,000,000



LANDSAT IMAGERY

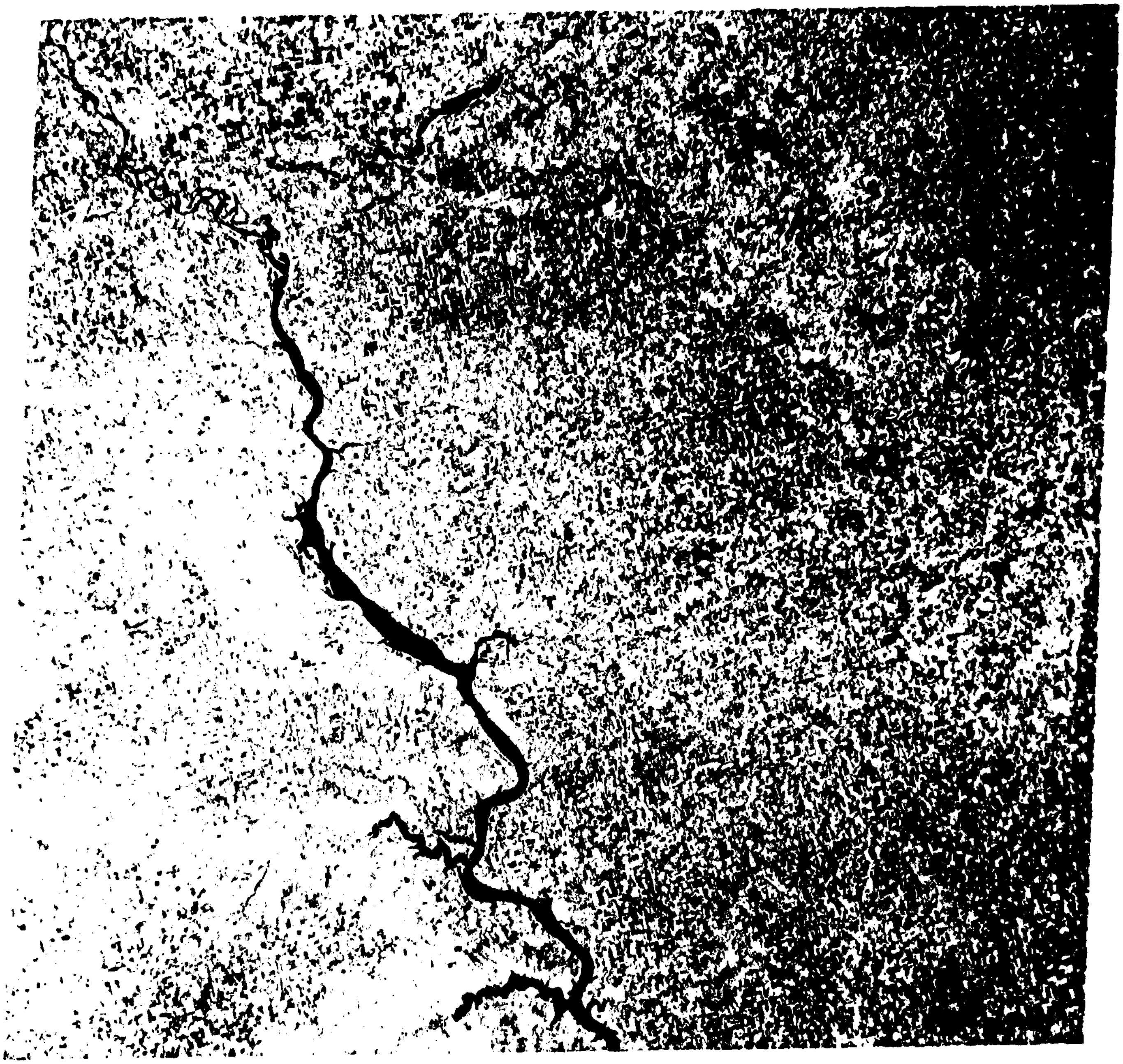
SCENE: 033-029
CENTER POINT: N 44D 38M/W 99D 13M
SCALE: 1:1,000,000

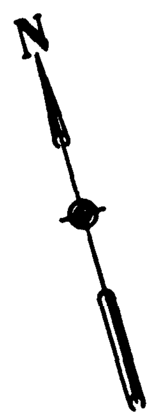




LANDSAT IMAGERY

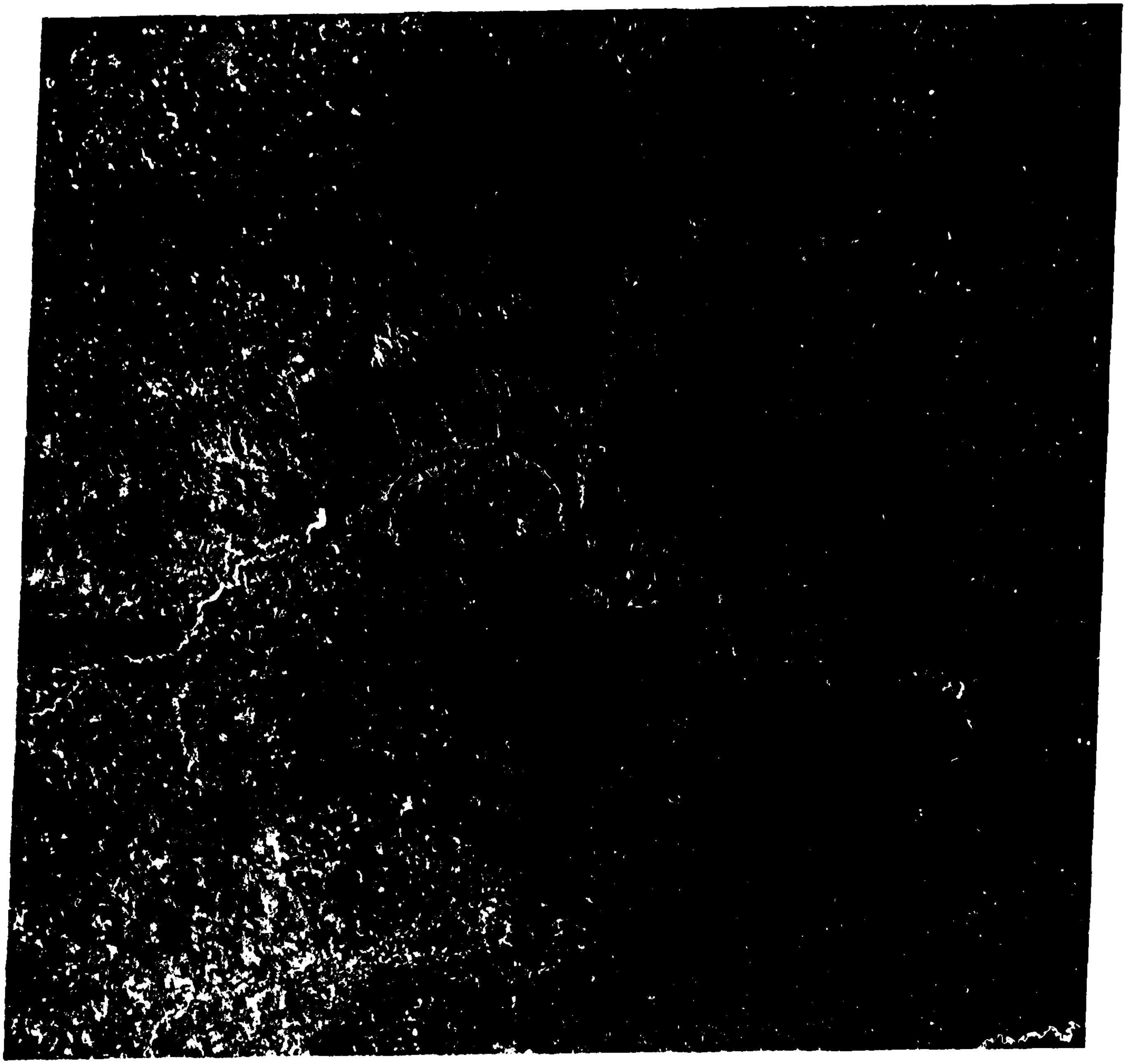
SCENE: 033-030
CENTER POINT: N 43D 13M/W 99D 45M
SCALE: 1:1,000,000

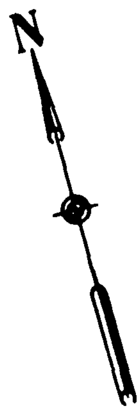




LANDSAT IMAGERY

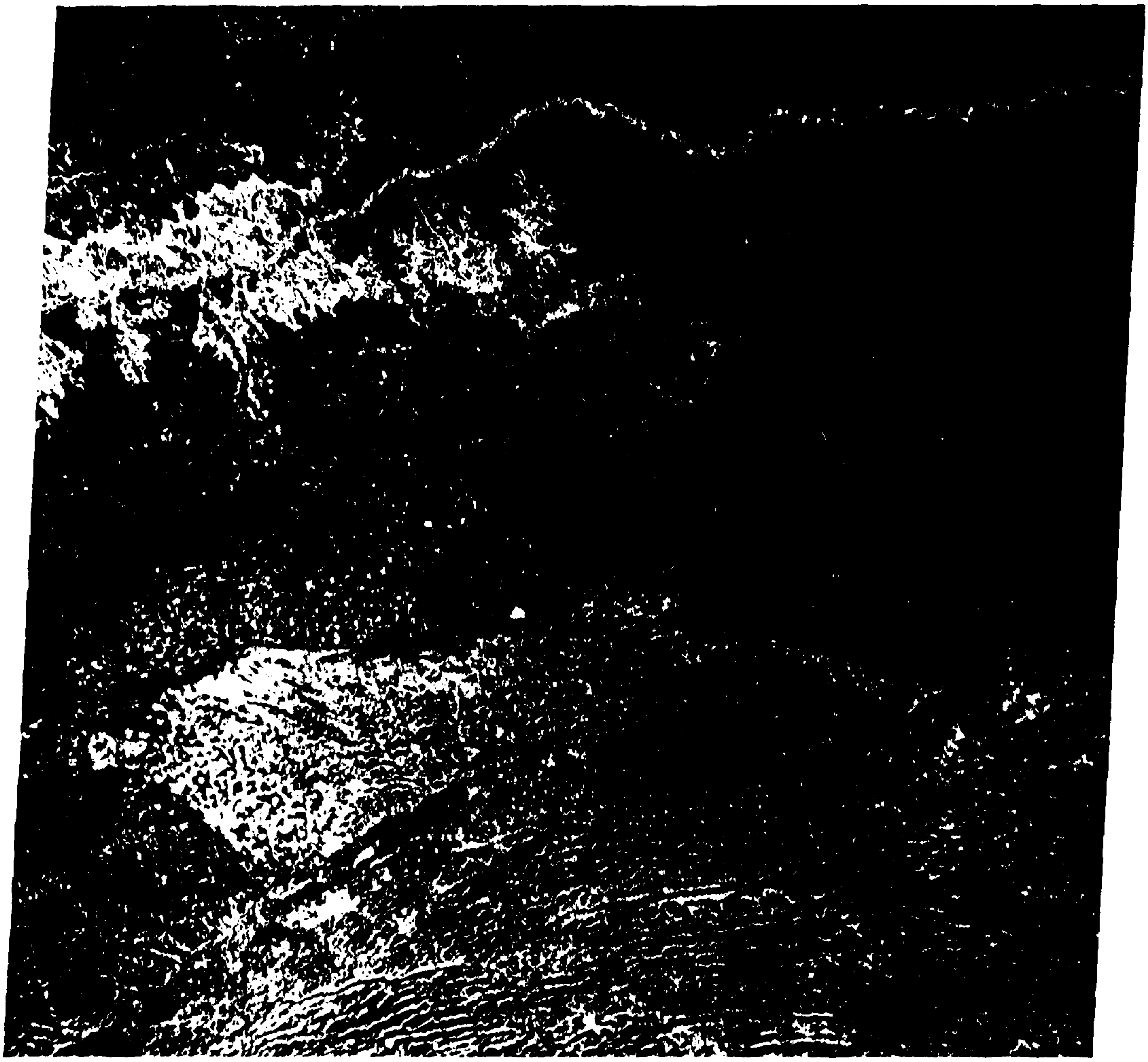
SCENE: 034-028
CENTER POINT: N 46D 02M/W 100D 06M
SCALE: 1:1,000,000





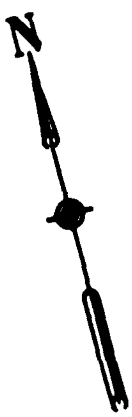
LANDSAT IMAGERY

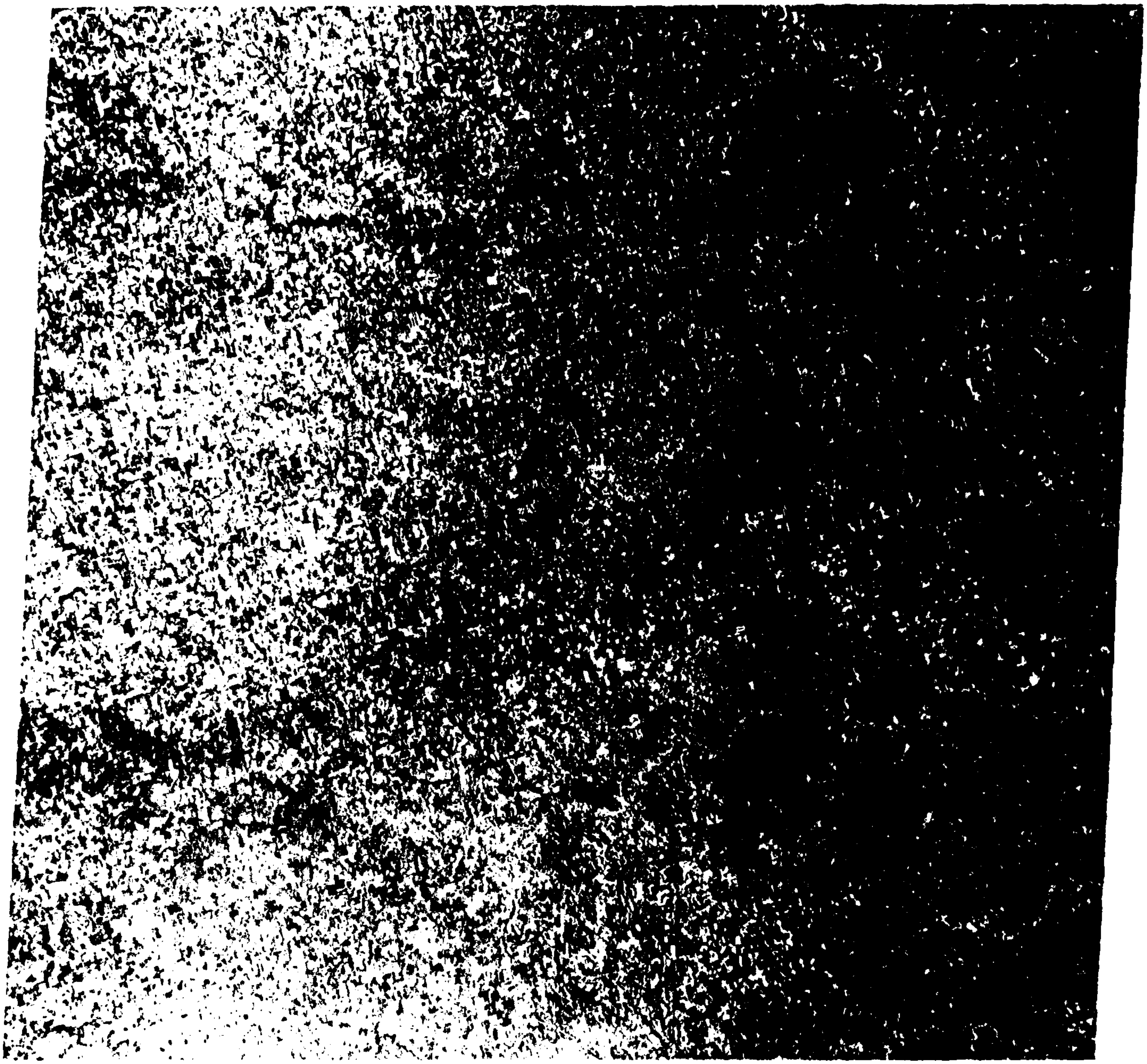
SCENE: 034-029
CENTER POINT: N 44D 37M/W 100D 39M
SCALE: 1:1,000,000

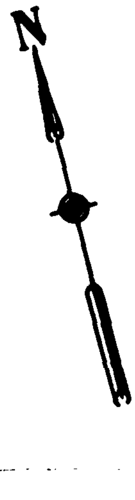


LANDSAT IMAGERY

SCENE: 034-030
CENTER POINT: N 43D 11M/W 101D 12M
SCALE: 1:1,000,000

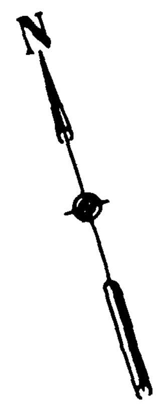






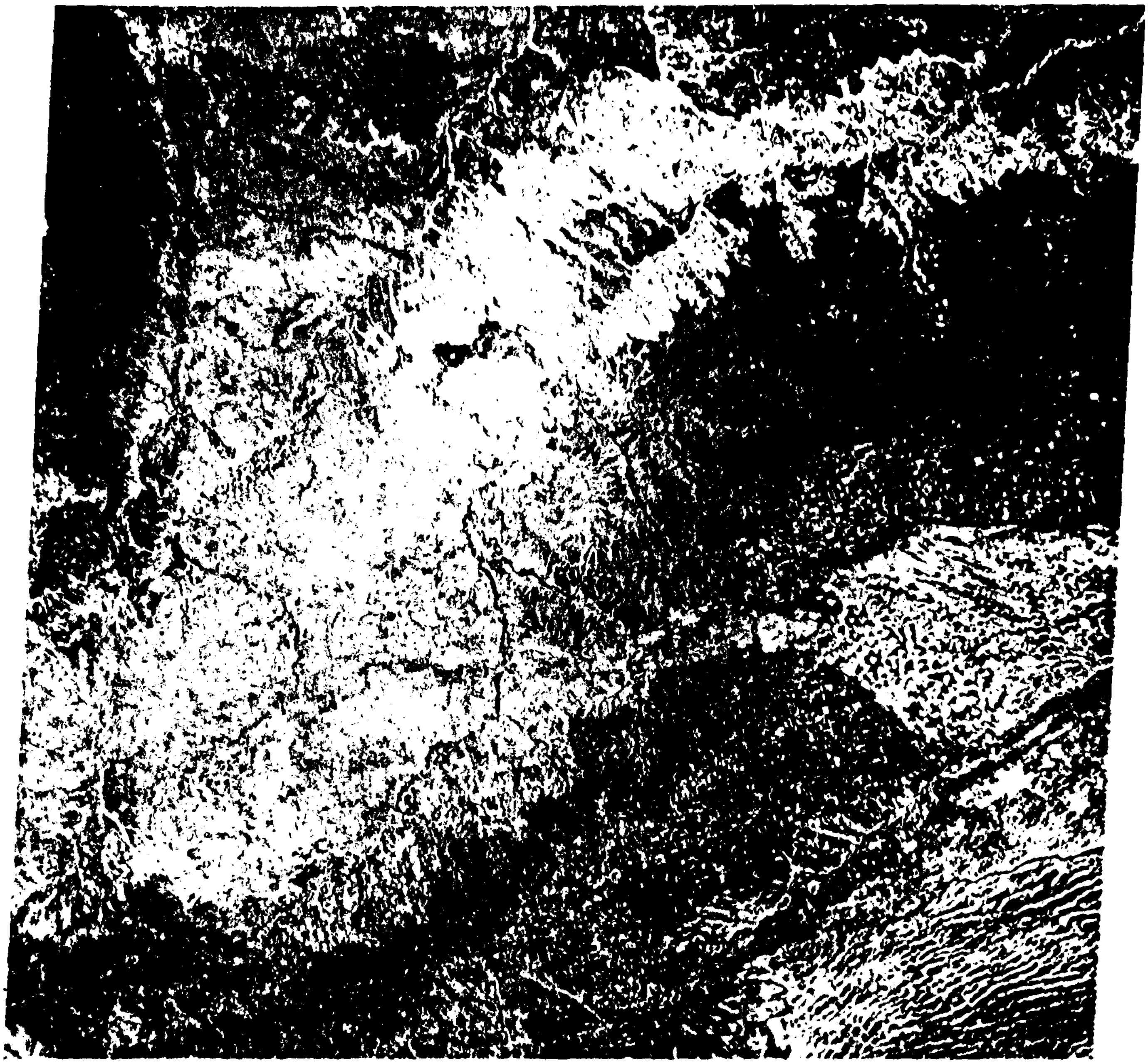
LANDSAT IMAGERY

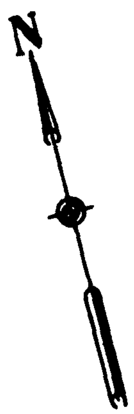
SCENE: 035-028
CENTERPOINT: N 46D 03M/W 101D 31M
SCALE: 1:1,000,000



LANDSAT IMAGERY

SCENE: 035-029
CENTER POINT: N 44D 38M/W 102D 05M
SCALE: 1:1,000,000





LANDSAT IMAGERY

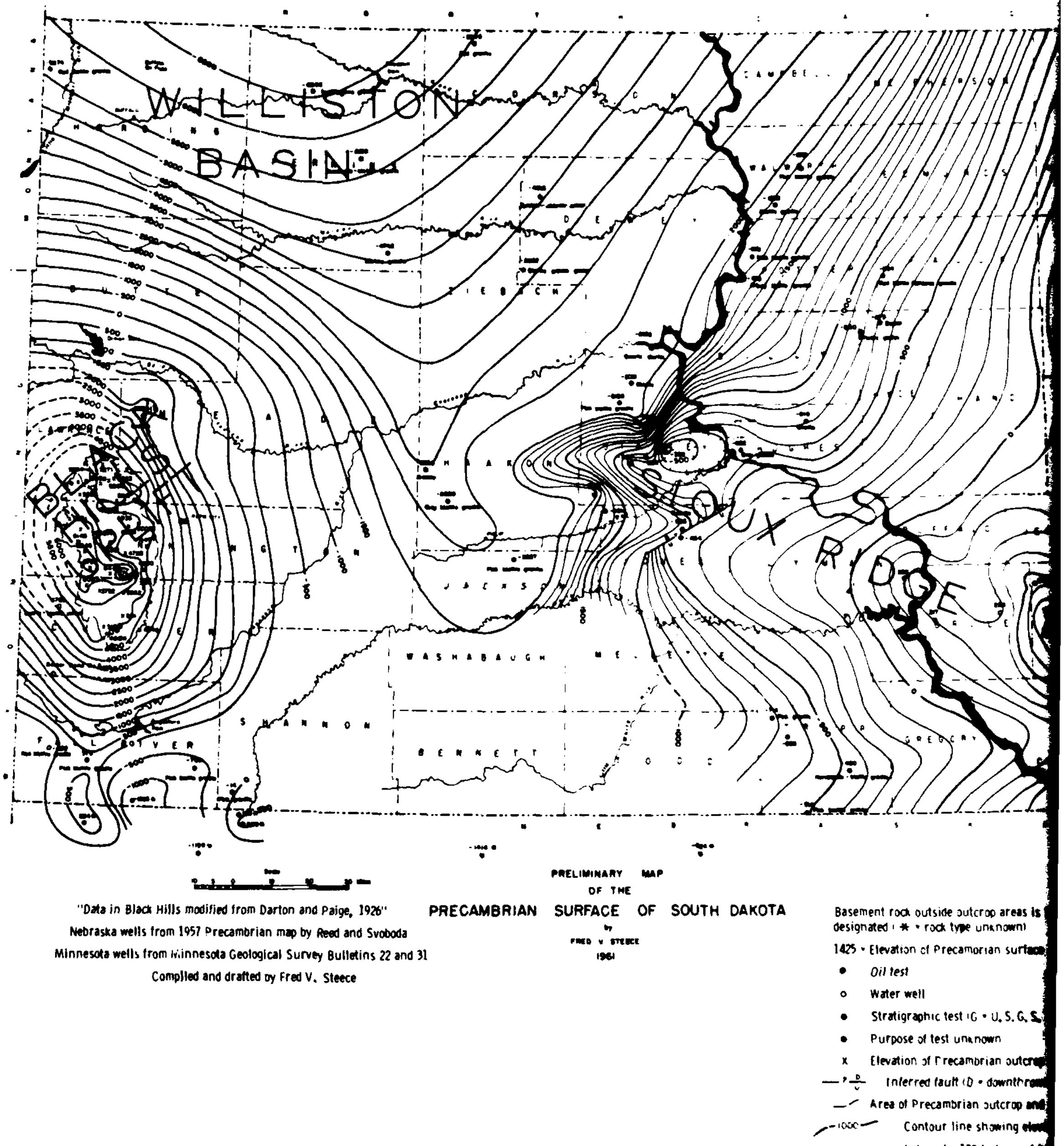
SCENE: 035-030
CENTER POINT: N 43D 13M/W 102D 37M
SCALE: 1:1,000,000

SOUTH DAKOTA GEOLOGICAL SURVEY

ALLEN F AGNEW, STATE GEOLOGIST

STATE OF SOUTH DAKOTA

ARCHIE GUBBRUD, GOVERNOR



PRELIMINARY MAP
OF THE
PRECAMBRIAN SURFACE OF SOUTH DAKOTA
by
FRED V. STEECE
1961

"Data in Black Hills modified from Darton and Paige, 1926"
Nebraska wells from 1957 Precambrian map by Reed and Svoboda
Minnesota wells from Minnesota Geological Survey Bulletins 22 and 31
Compiled and drafted by Fred V. Steece

Basement rock outside outcrop areas is
designated (* = rock type unknown)

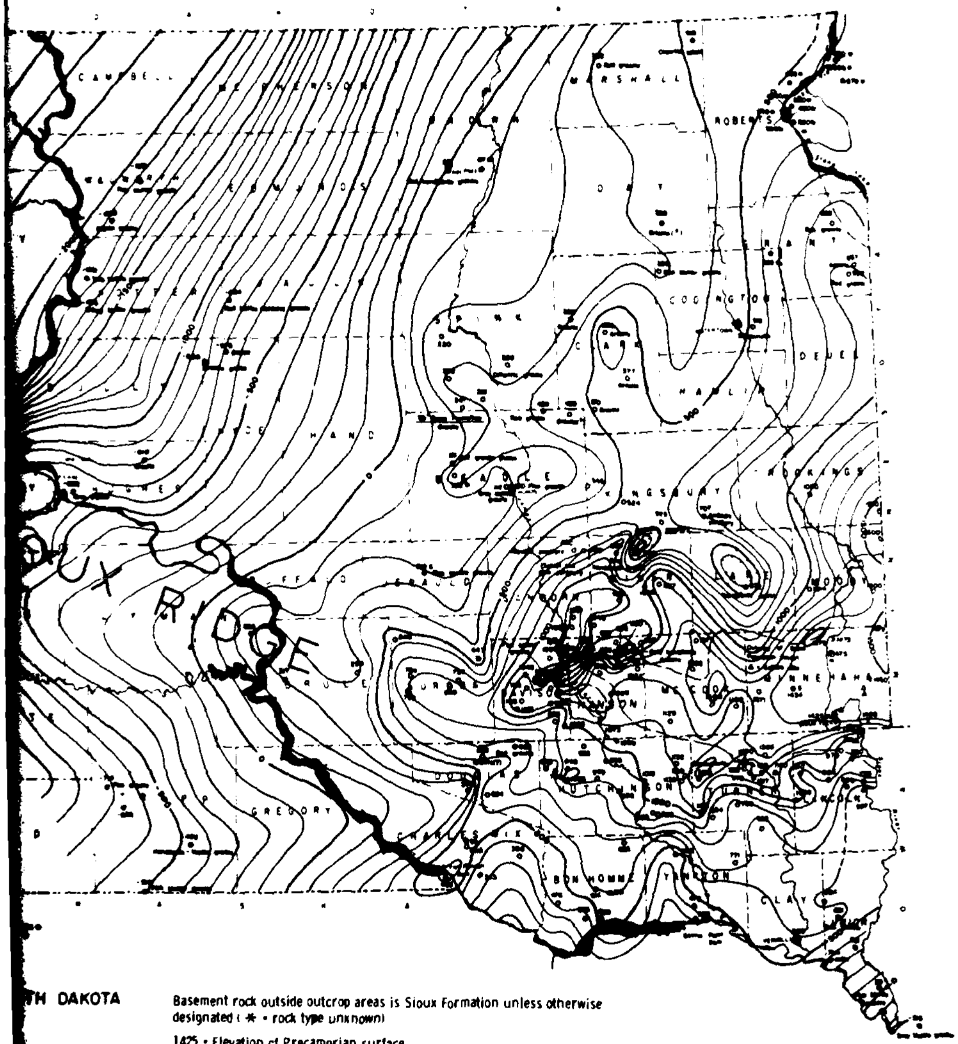
1425 = Elevation of Precambrian surface

- • Oil test
- o Water well
- • Stratigraphic test (G = U. S. G. S.
- • Purpose of test unknown
- x Elevation of Precambrian outcrop
- Inferred fault (D = downthrown
- Area of Precambrian outcrop and
- Contour line showing elev
  Interval = 100 feet except

...TE OF SOUTH DAKOTA

MINERAL RESOURCES INVESTIGATIONS

MAP NO 2



...TH DAKOTA

Basement rock outside outcrop areas is Sioux Formation unless otherwise designated (* = rock type unknown)

1425 = Elevation of Precambrian surface

- • Oil test
- o Water well
- • Stratigraphic test (G = U.S.G.S. ; S = S.D.G.S.)
- • Purpose of test unknown
- x Elevation of Precambrian outcrop
- Inferred fault (D = downthrown side, U = upthrown side)
- Area of Precambrian outcrop and sub-glacial drift outcrop
- 1000 Contour line showing elevation of Precambrian surface

Interval = 100 feet except below -2000 and near Black Hills

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

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CORPS OF ENGINEERS
OMAHA, NEBRASKA

MISSOURI RIVER
OAHE DAM – OAHE LAKE
CAUSATIVE FAULT STUDY
PRECAMBRIAN SURFACE
OF SOUTH DAKOTA

CHIEF GEOLOGY SECTION

DATE MARCH 1982

SCALE AS SHOWN

SPEC NO DACA45

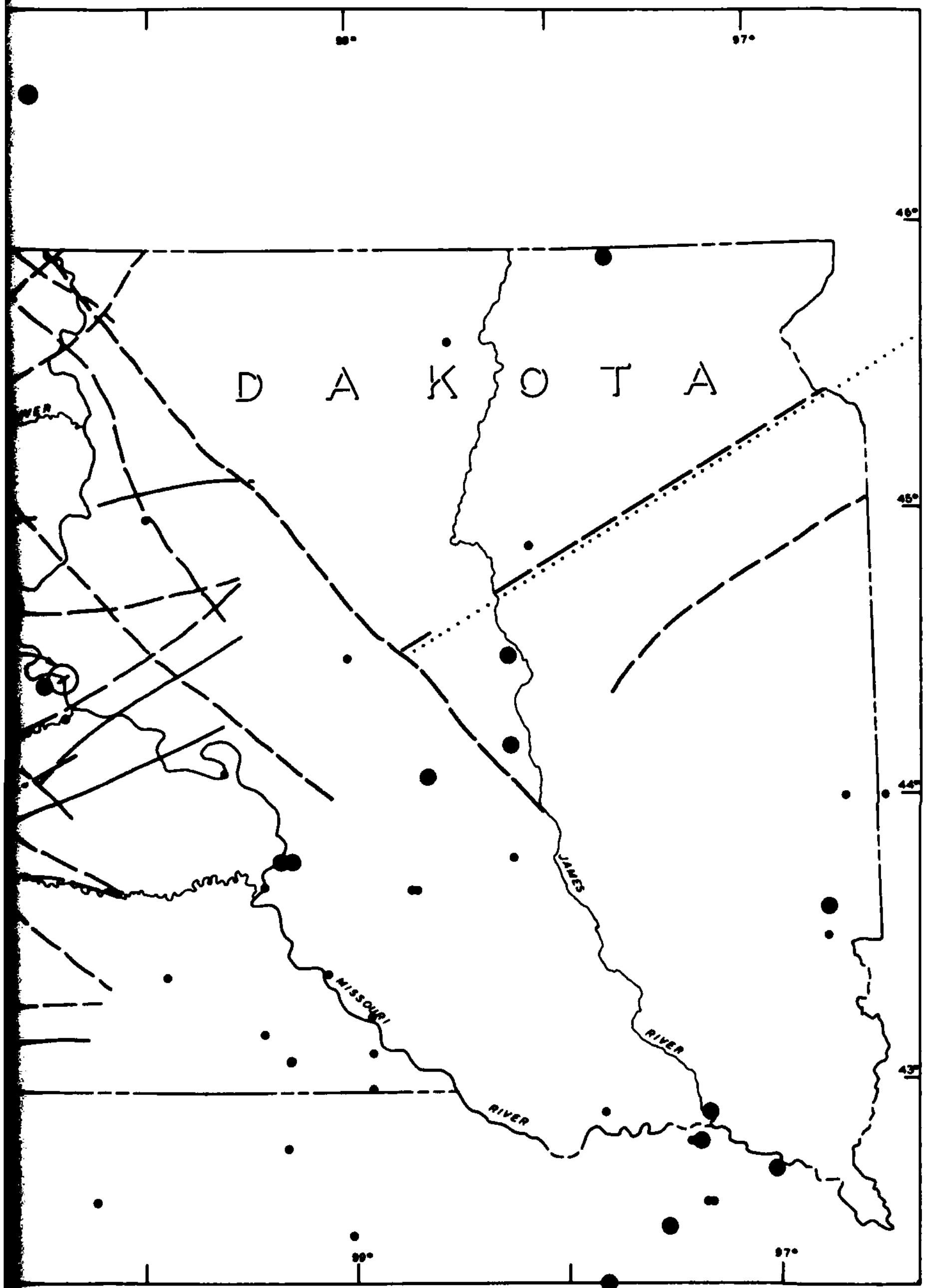
SAFETY PAYS

THIS PLAN ACCOMPANIES CONTRACT NO. DACA45 MODIFICATION NO.

$$ – THINK VALUE ENGINEERING – $$

PLATE 2

103°
101°
99°
46°
45°
44°
43°
S O U T H
D A K
RIVER
MOREAU
RIVER
OAHE
DAM
CHEYENNE
BAD RIVER
WHITE RIVER
MISSOURI
103°
101°
99°
SCALE 1 1,000,000



1:1,000,000

LEGEND

- $3.0 \le m_b \le 3.9$ / $4.0 \le m_b \le 4.9$ — Earthquake Epicenters, $M_b > 3.0$ (Nutti and Hermann, 1978)
- Mapped Fault (Raymond & King, 1976)
- Inferred Basement Fault (Steece, 1961)
- Inferred Basement Fault (Lidiak, 1971)
- Precambrian Terrane Boundary (Morey & Sims, 1976)
- Observed by two workers / Observed by one worker — Lineaments (Shurr, 1978)
- Well defined by data / Poorly defined by data — Lineaments (Raines, 1979)

DATE | DESCRIPTION

REVISIONS

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OMAHA, NEBRASKA

MISSOURI RIVER
OAHE DAM - OAHE LA
CAUSATIVE FAULT S
PUBLISHED DATA
LINEAMENTS FAULTS AND
EARTHQUAKE EPICENTERS

SCALE: AS SHOWN

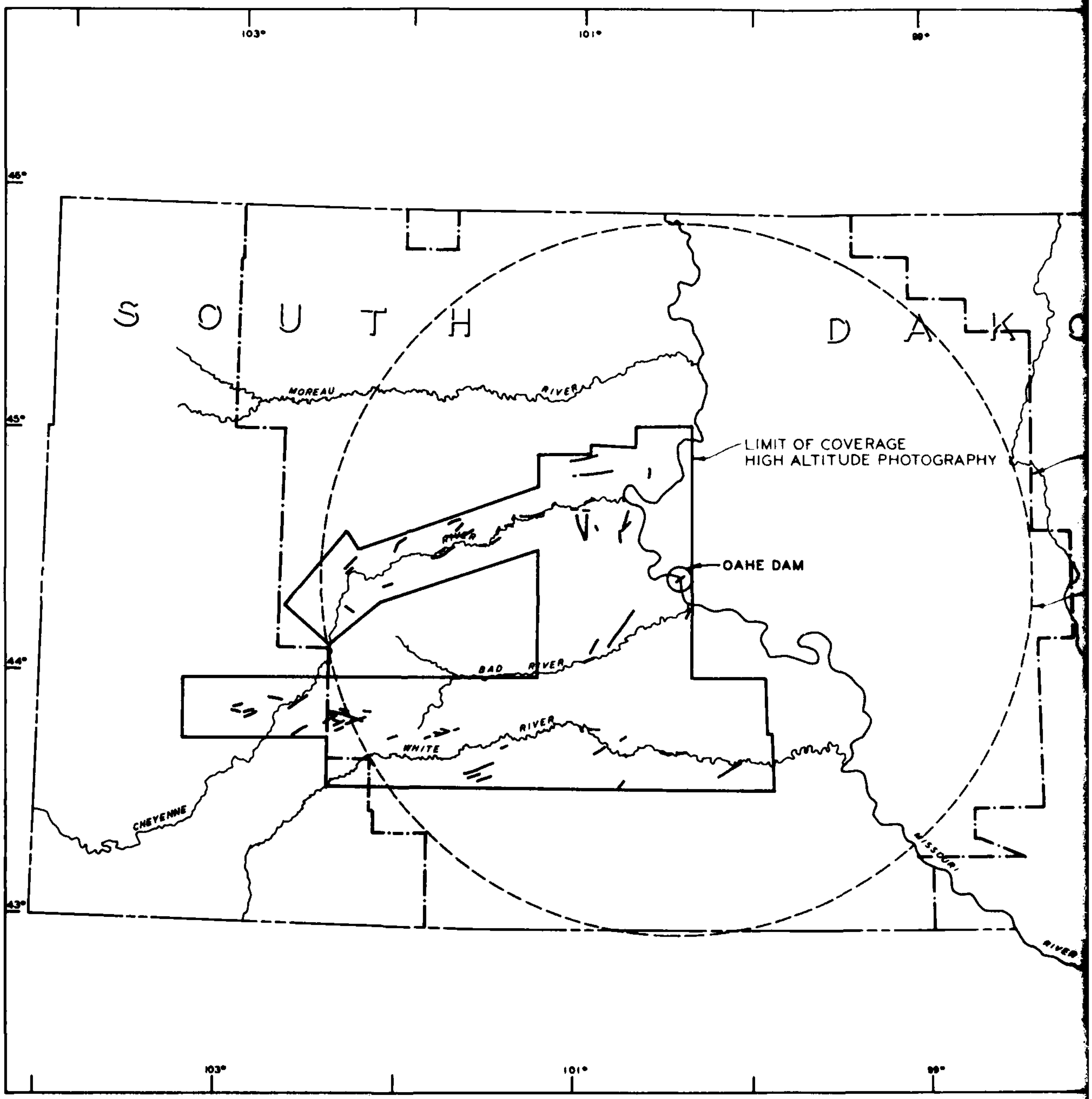
SAFETY PAYS

THIS PLAN ACCOMPANIES CONTRACT NO.
DACA45
MODIFICATION NO.

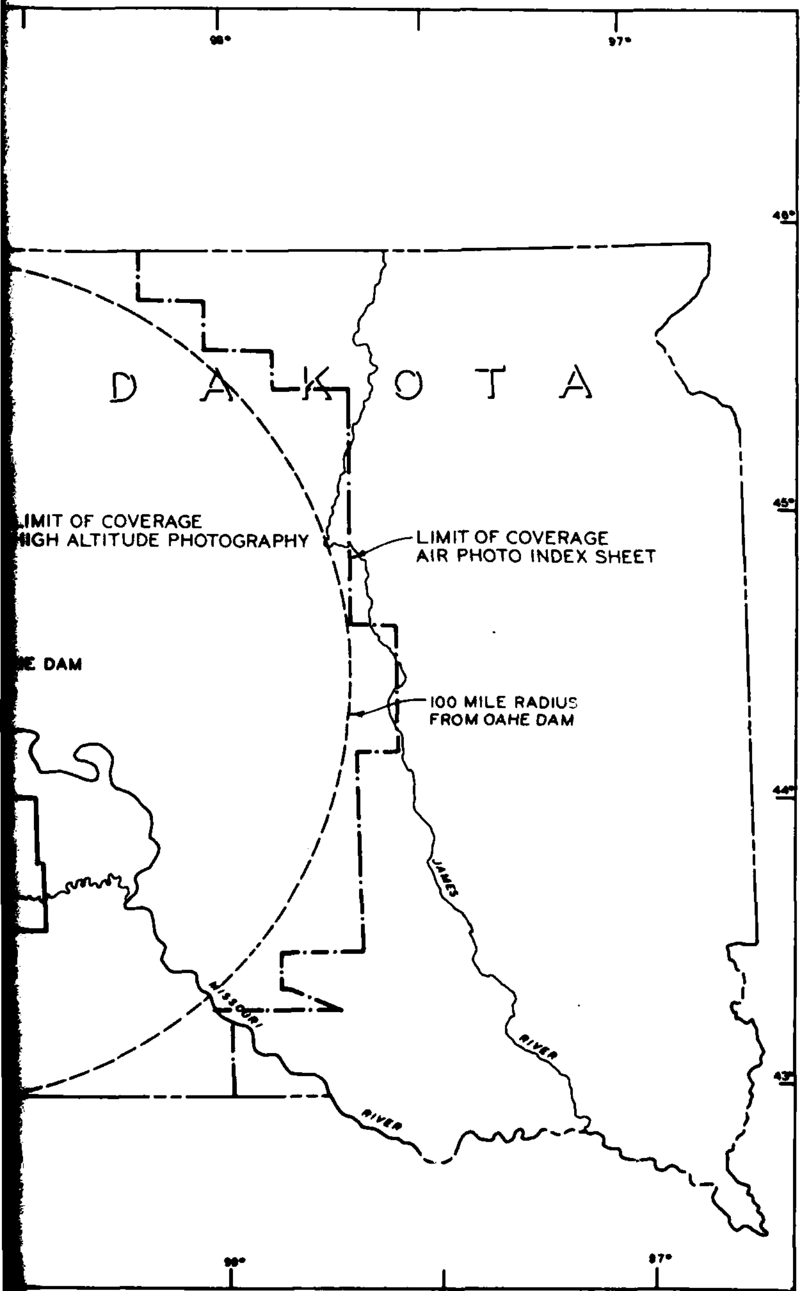
$$ - THINK VALUE ENGINEERING - $$

1

2



103°
101°
99°
46°
45°
44°
43°
S O U T H D A K O
MOREAU RIVER
LIMIT OF COVERAGE
HIGH ALTITUDE PHOTOGRAPHY
OAHE DAM
BAD RIVER
WHITE RIVER
CHEYENNE
MISSOURI
RIVER
SCALE 1:1,000,000



NOTE: Linear features were mapped at a scale of approximately 1:125,000. Trends of these features are shown diagrammatically in red.

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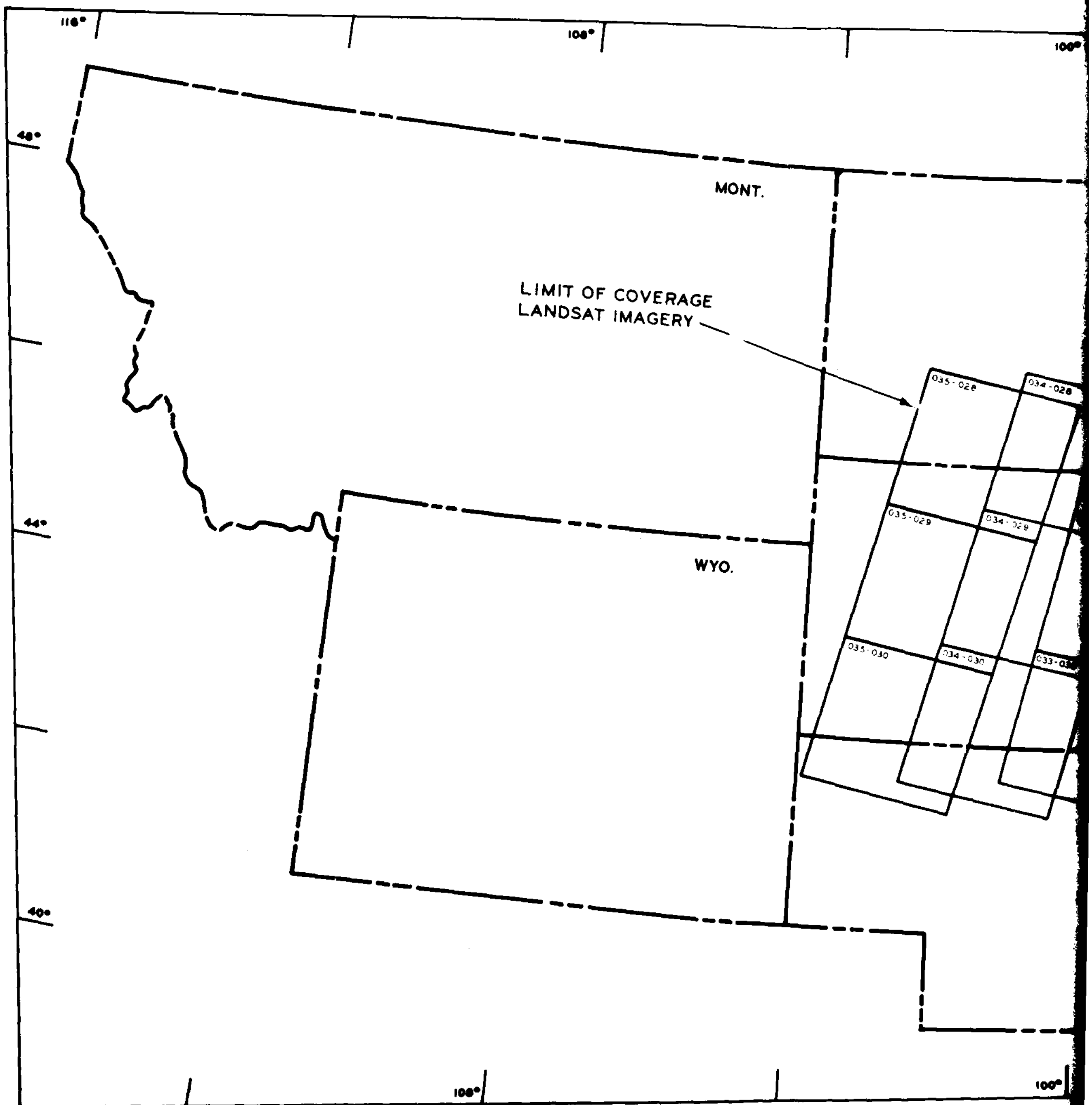
OMAHA, NEBRASKA

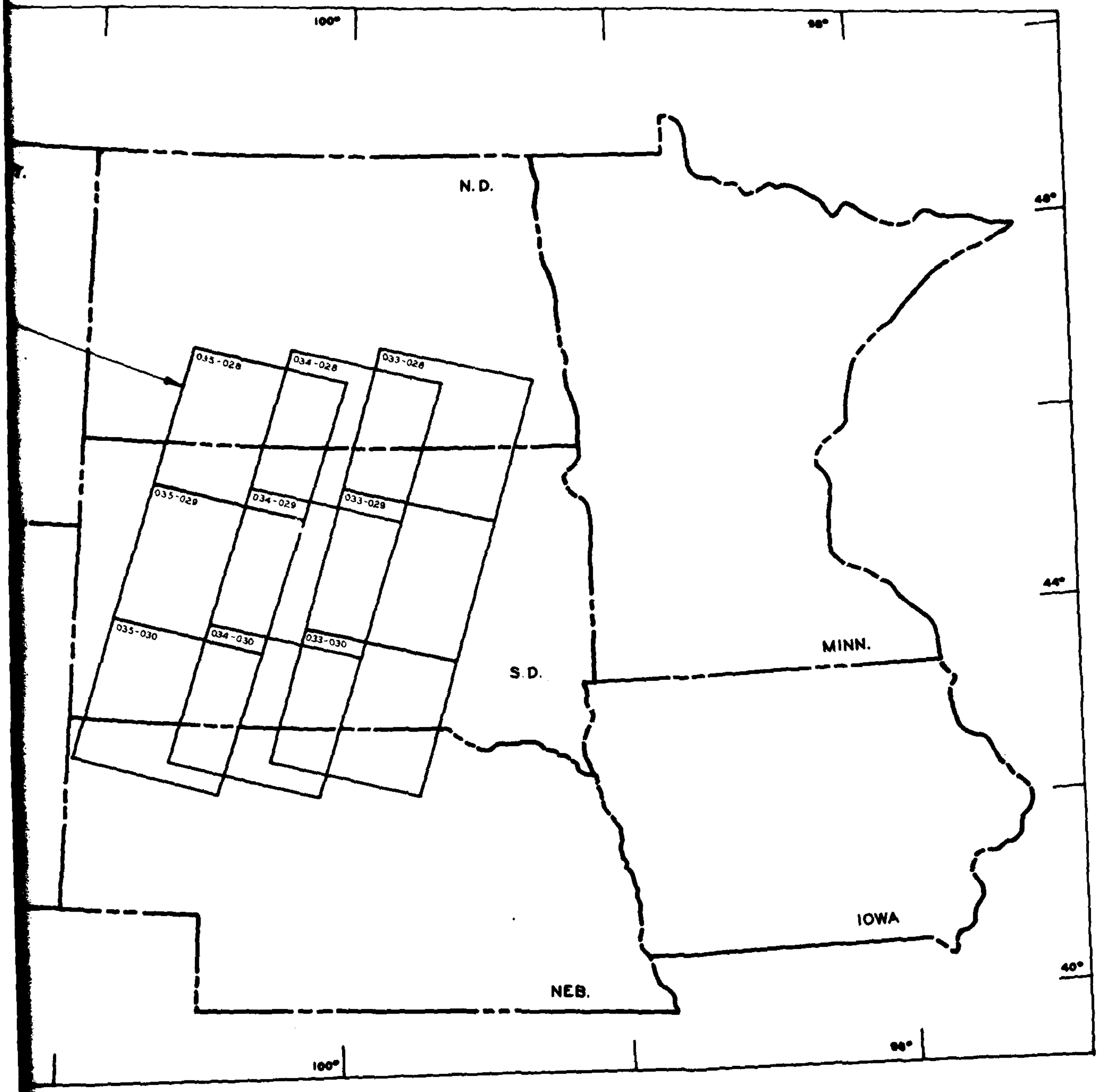
MISSOURI RIVER
OAHE DAM - OAHE LAKE
CAUSATIVE FAULT STUDY
COVERAGE OF AIR PHOTO INDEX SHEETS AND LINEAR FEATURES OBSERVED ON HIGH ALTITUDE PHOTOGRAPHY

JULY 1980

SAFETY PAYS

THIS PLAN ACCOMPANIES CONTRACT NO.


116°
108°
100°
48°
44°
40°
MONT.
WYO.
LIMIT OF COVERAGE
LANDSAT IMAGERY
035-028
034-028
035-029
034-029
035-030
034-030
033-030
108°
100°



DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

MISSOURI RIVER
OAHE DAM ~ OAHE LAKE
CAUSATIVE FAULT STUDY
COVERAGE OF LANDSAT IMAGERY

MARCH 1982

SCALE AS SHOWN

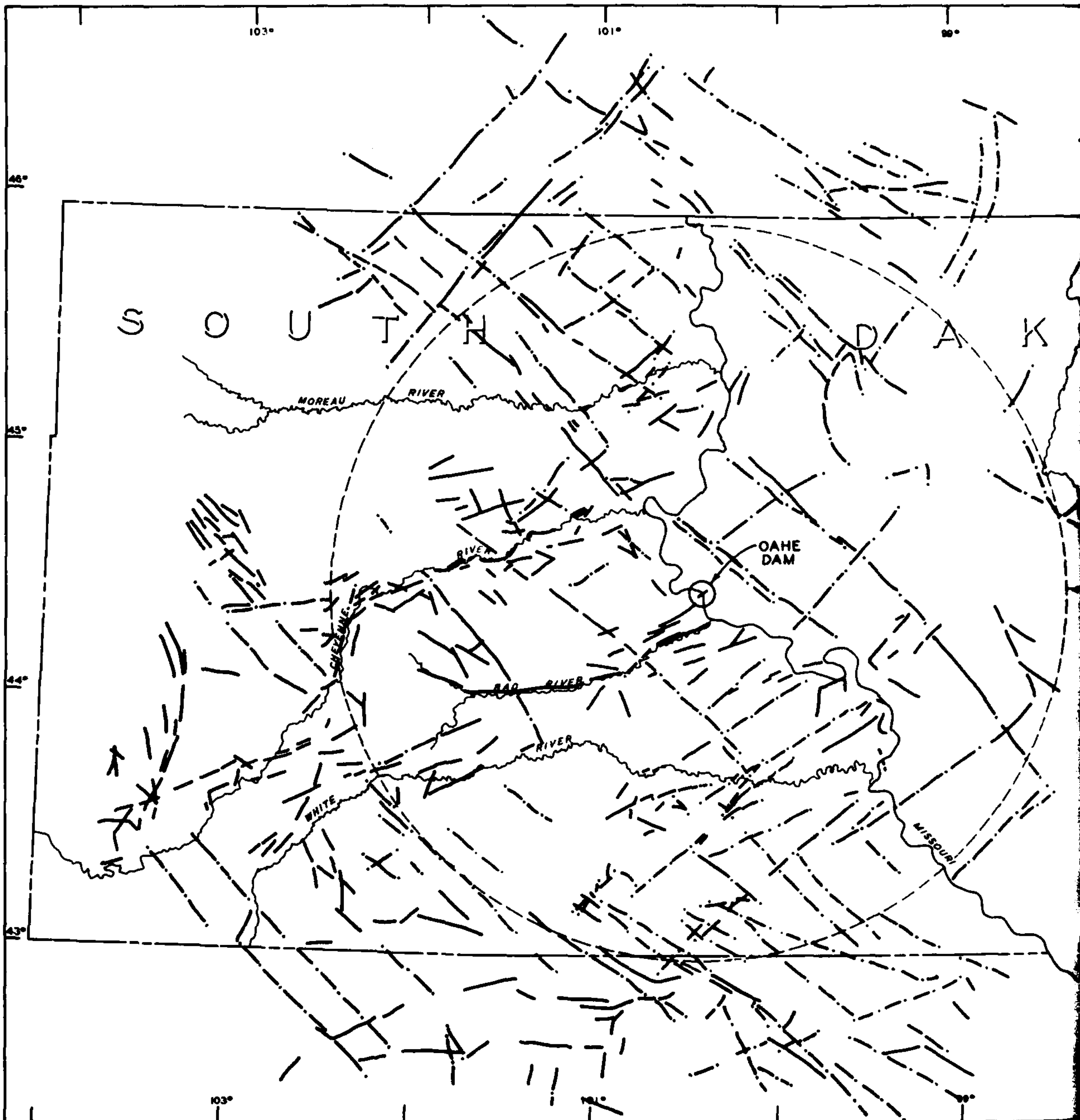
SAFETY PAYS

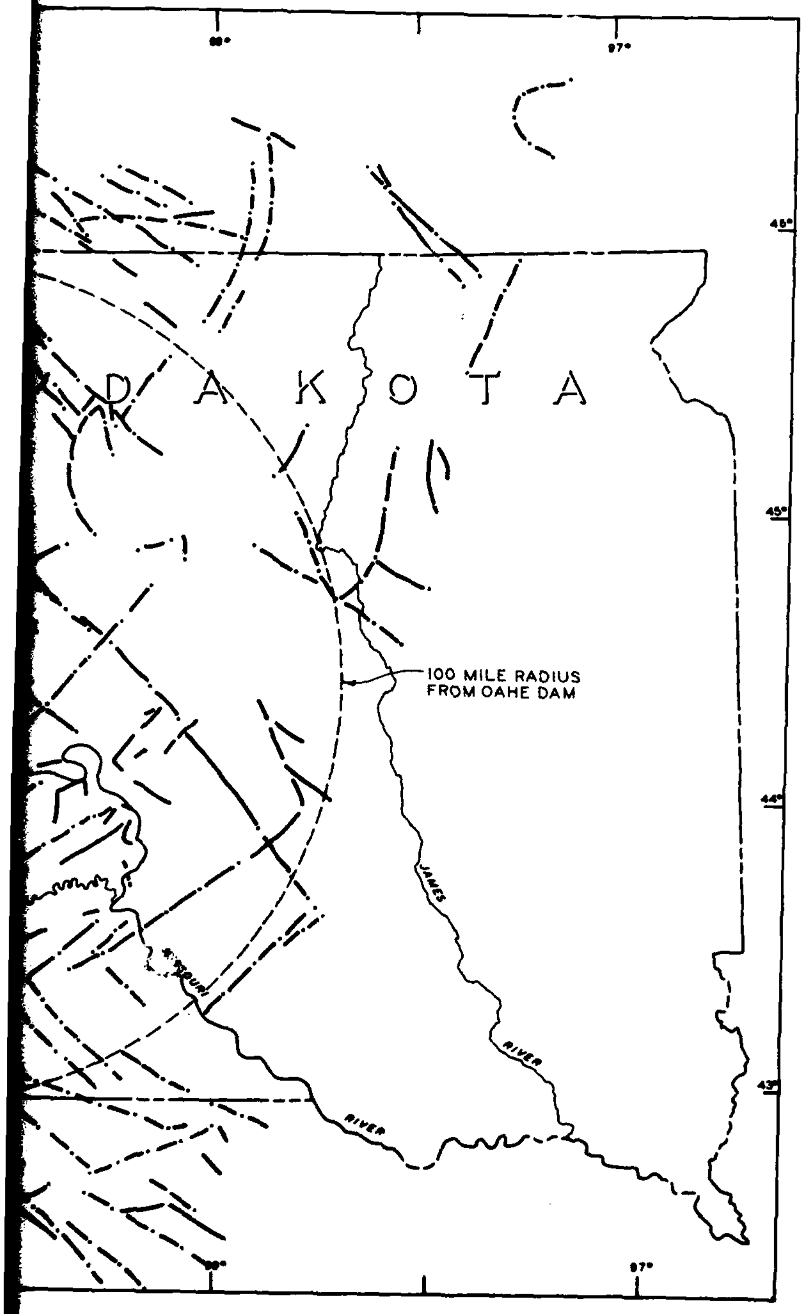
THIS PLAN ACCOMPANIES CONTRACT NO.
DACA45 SPECIFICATION NO.

PLATE 4

$$ – THINK VALUE ENGINEERING – $$

1 2


103°
101°
99°
46°
45°
44°
43°
S O U T H D A K
MOREAU RIVER
CHEYENNE RIVER
BAD RIVER
WHITE RIVER
MISSOURI
OAHE DAM
SCALE 1:1,000,000



LEGEND

Well defined	}	Linear features observed on Landsat
Poorly defined	}	
Landsat features also found on high altitude photography		

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

MISSOURI RIVER
OAHE DAM – OAHE LAKE
CAUSATIVE FAULT STUDY
LINEAR FEATURE MAP

DATE: JULY 1980

SCALE: AS SHOWN

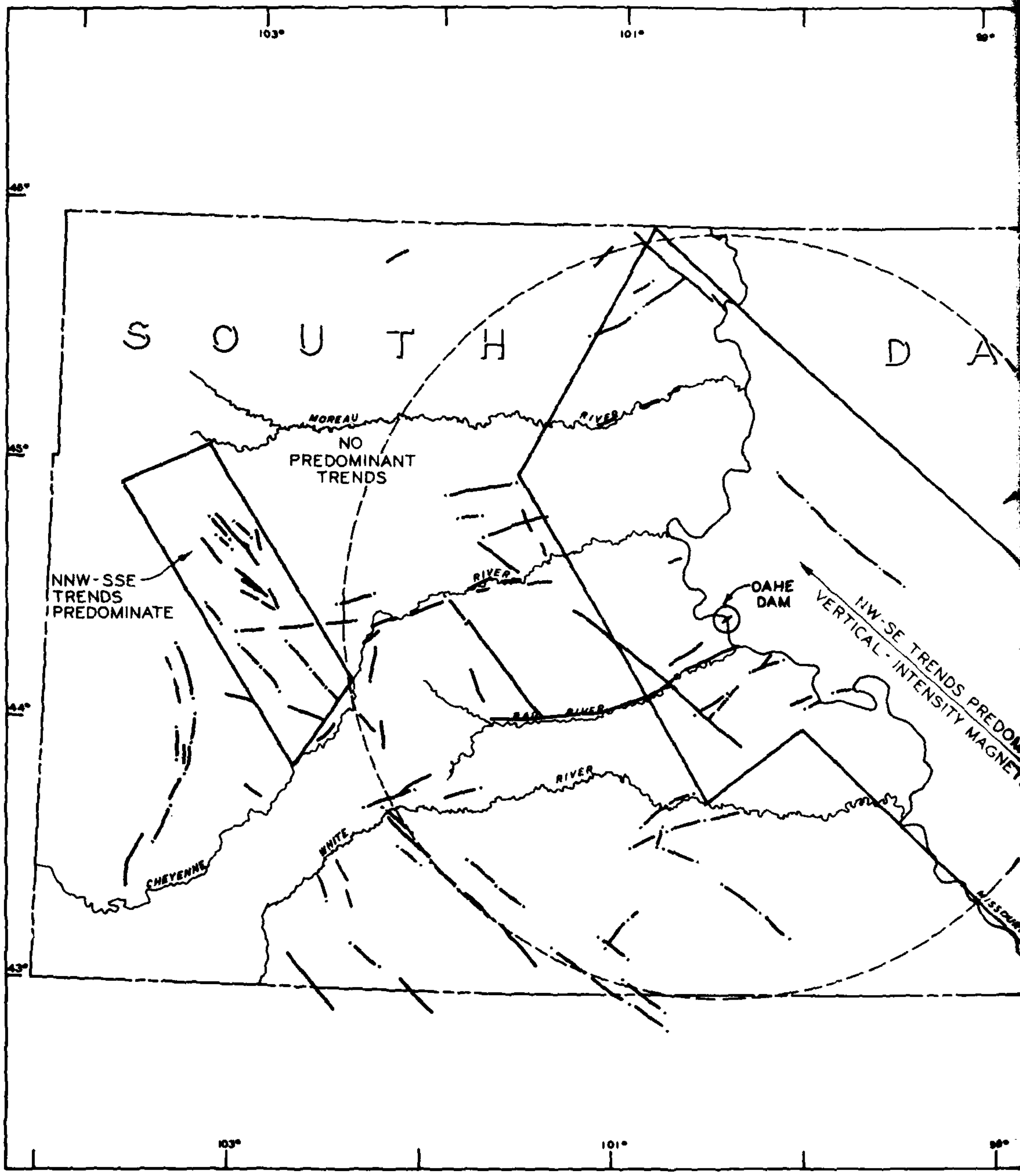
THIS PLAN ACCOMPANIES CONTRACT No.

THINK VALUE ENGINEERING

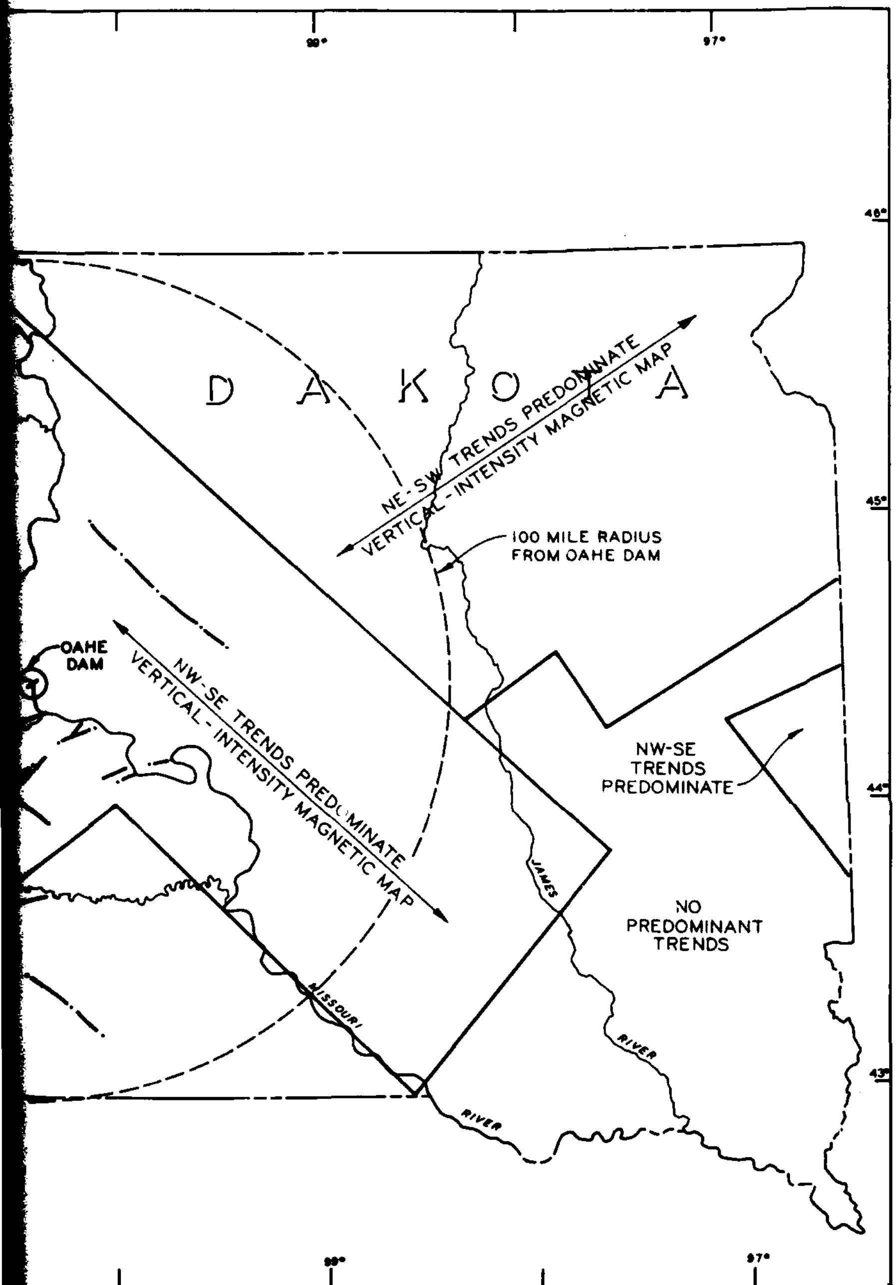
PLATE 5

1

2



SCALE 1:1,000,000



,000

LEGEND

- Poorly defined
- Well defined

Features shown on linear feature map (Plate 5) which follow trend of lineaments by Shurr, 1978 or Raines, 1979 (Plate 2).

SAFETY PAYS

THIS PLAN ACCOMPANIES CONTRACT NO.
DACA45 MODIFICATION NO.

DATE | DESCRIPTION | MADE | APPR'D

REVISIONS

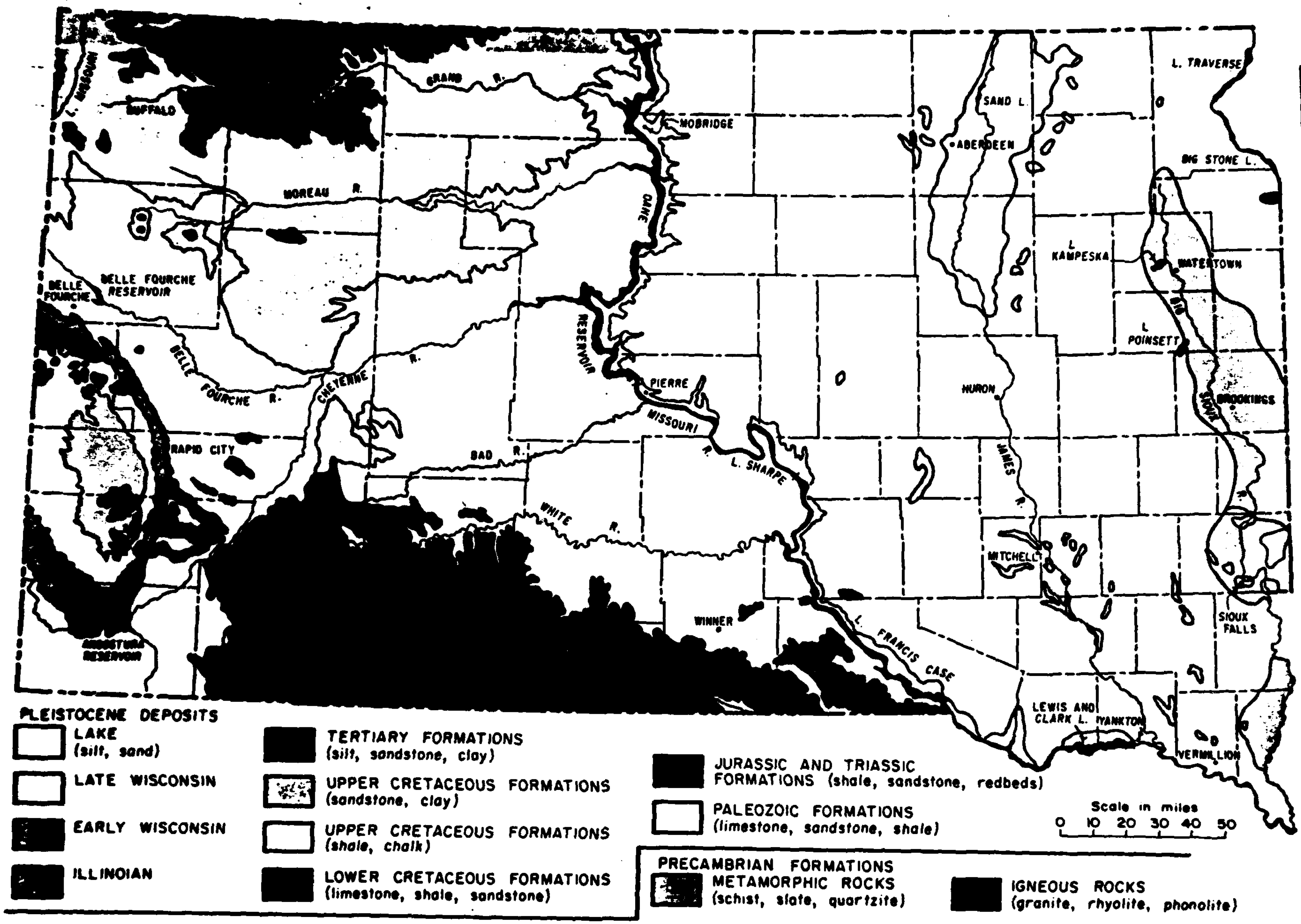
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

MISSOURI RIVER
OAHE DAM – OAHE LAKE
CAUSATIVE FAULT STUDY
LINEAR FEATURE COMPARISON WITH PUBLISHED DATA AND PREDOMINANT MAGNETIC TRENDS

DATE: MARCH 1982

SCALE: AS SHOWN

$$ – THINK VALUE ENGINEERING – $$



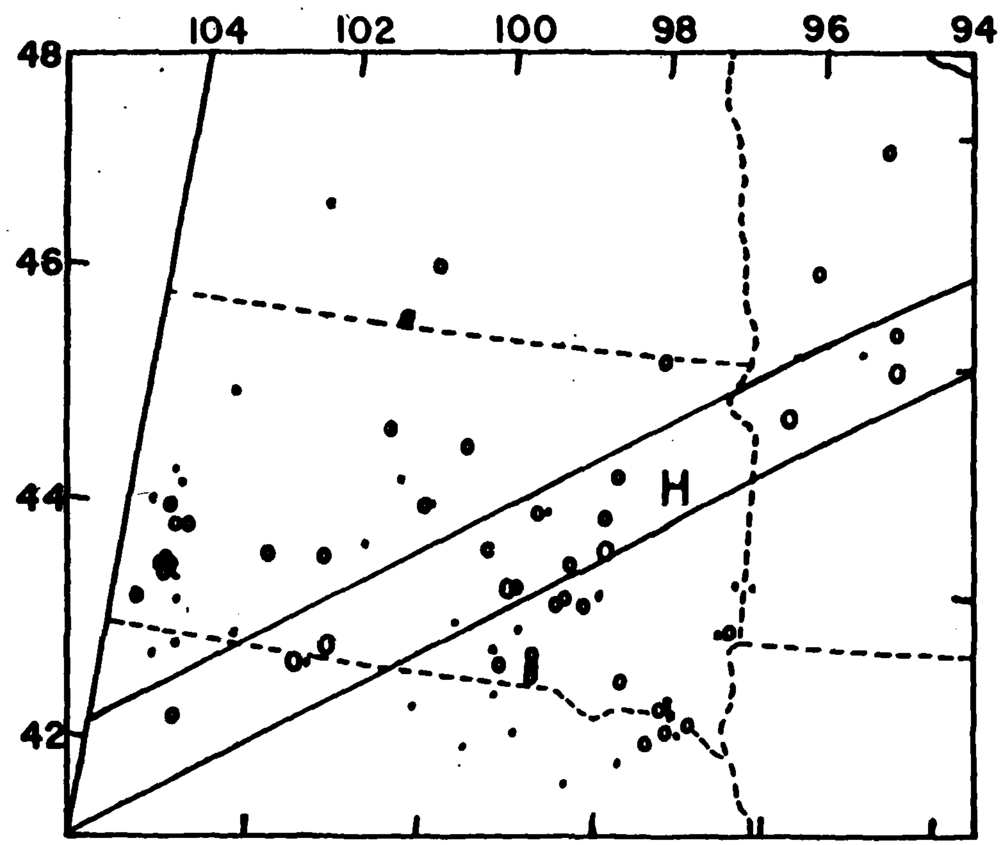
DEPARTMENT OF NATURAL RESOURCE DEVELOPMENT
SOUTH DAKOTA GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

STATE OF SOUTH DAKOTA
Richard F Kneip, Governor

EDUCATIONAL SERIES
Map One

GEOLOGIC MAP OF SOUTH DAKOTA

PLATE 7

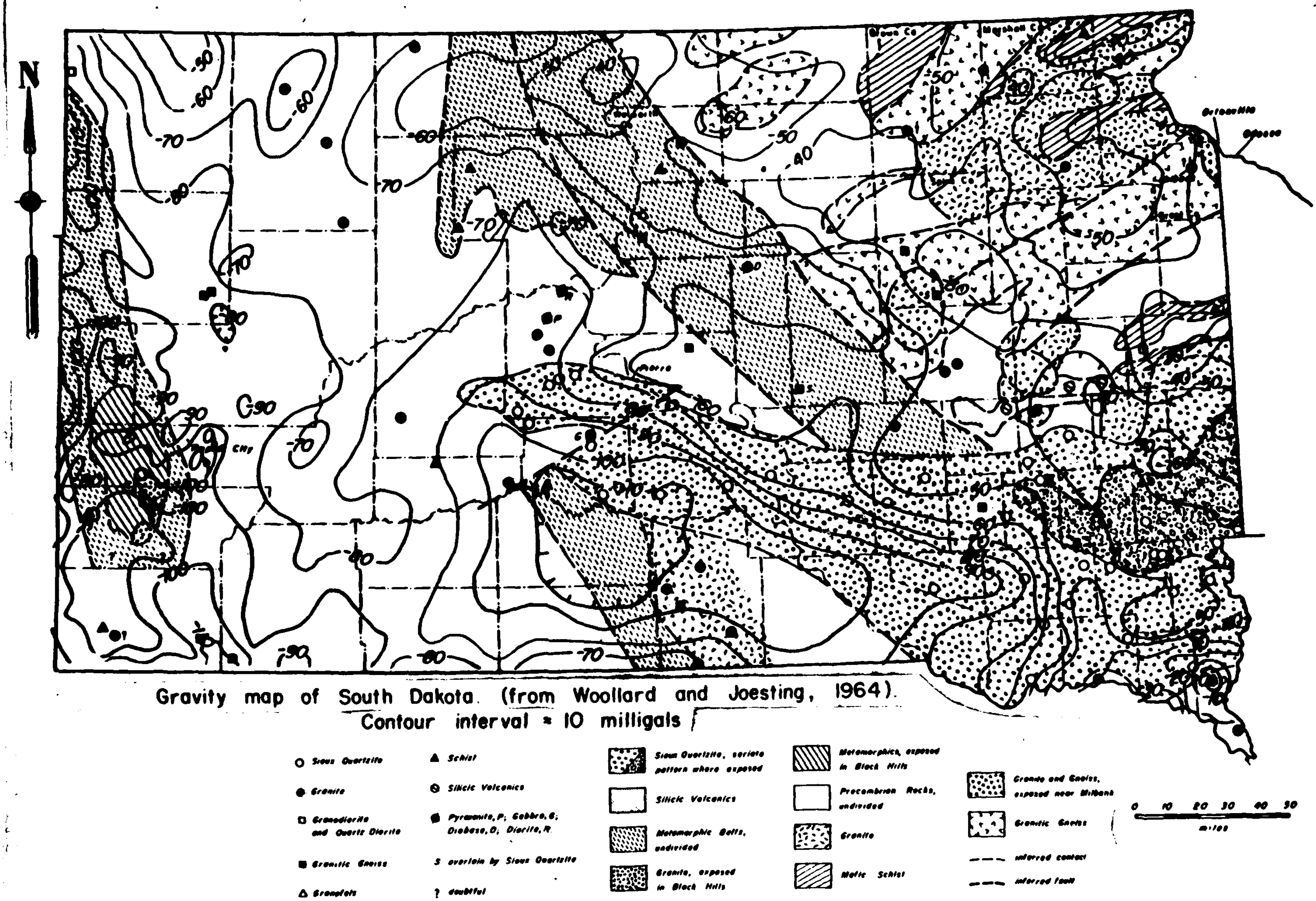


• $3.0 \leq m_b \leq 3.7$
• $3.8 \leq m_b \leq 4.4$
o $4.5 \leq m_b \leq 5.1$

H Colorado Lineament

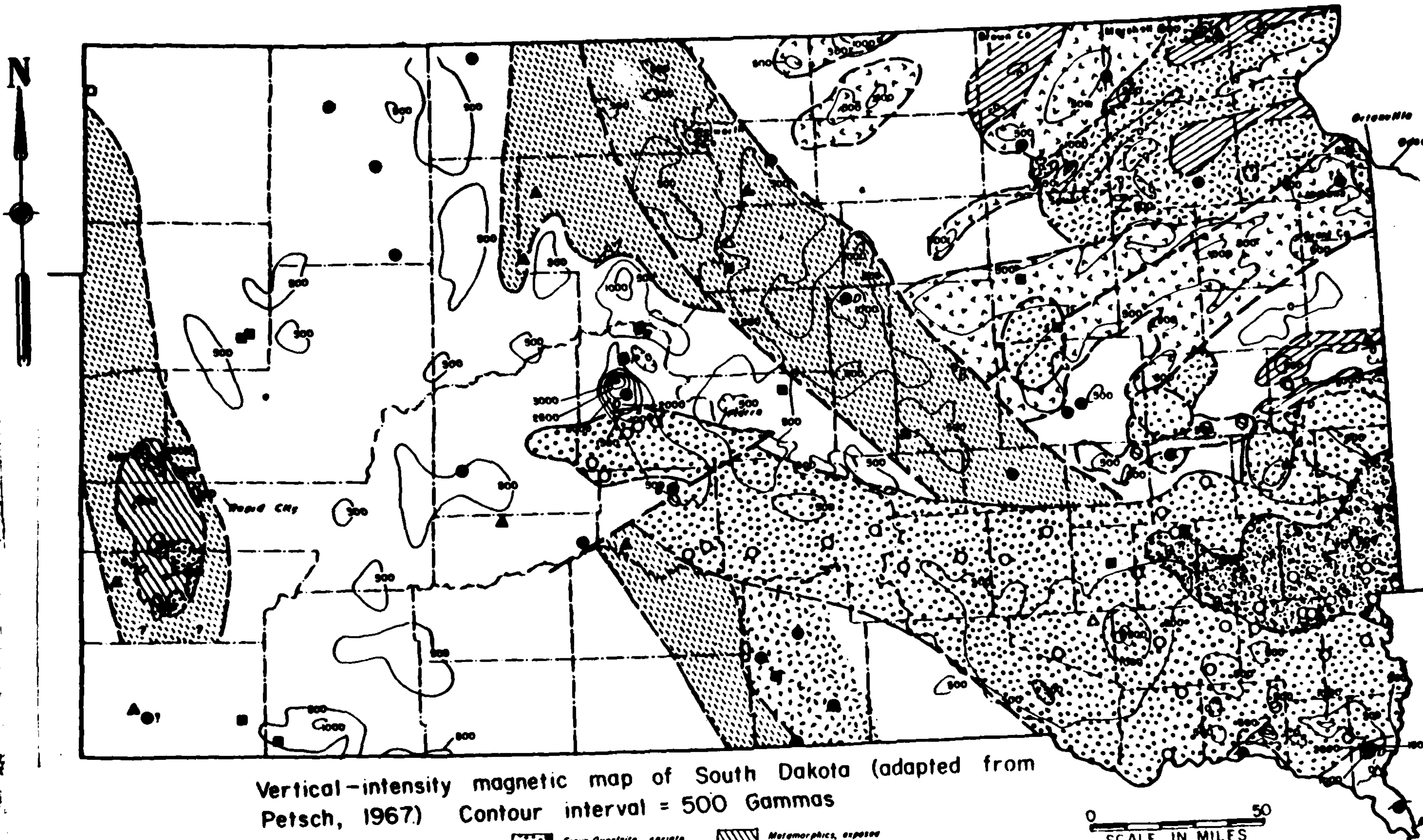
Map showing known earthquakes of $m_b \geq 3.0$ in the area with vertices 48N, 104W; 48N, 94W; 42N, 104W; 42N, 94W. (Nuttli and Brill, 1981)

PLATE 8

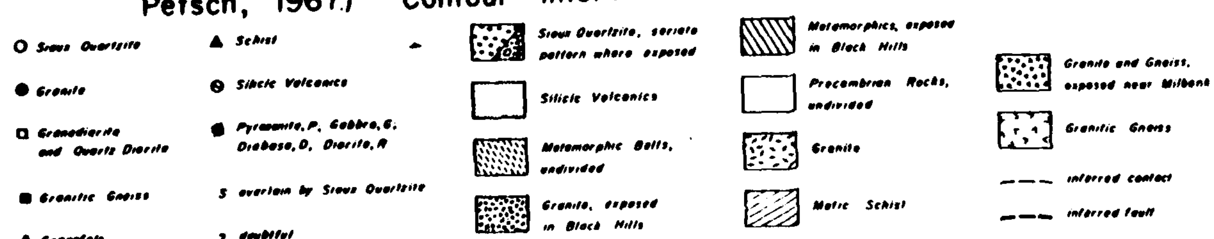


Gravity map of South Dakota. (from Woollard and Joesting, 1964).
Contour interval = 10 milligals

Geological map of the Precambrian rocks of South Dakota.
(from Lidiak, 1971)



Vertical-intensity magnetic map of South Dakota (adapted from Petsch, 1967) Contour interval = 500 Gammas



Geological map of the Precambriar rocks of South Dakota.
(from Lidiak, 1971)